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DEPARTMENT OF THE INTERIOR

UNITED STATES BUREAU OF MINES
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REVIEW OF LITERATURE ON EFFECTS OF BREATHING DUSTS WITH SPECIAL REFERENCE TO SILICOSIS

PART II-B

CHAPTER 4. PREVENTION OF DUST DISEASES
(SECTIONS 3 - 5)

BY

D. HARRINGTON AND SARA J. DAVENPORT

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

REVIEW OF LITERATURE ON EFFECTS OF BREATHING DUSTS WITH SPECIAL REFERENCE TO SILICOSIS[1]

PART II-B

By D. Harrington[2] and Sara J. Davenport[3]

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CHAPTER 4. PREVENTION OF DUST DISEASES (CONT'D)

Section 3. - Engineering Control in the Prevention of Dust Diseases

Hatch (260) made the following pertinent statement regarding the present status of engineering design of dust-control equipment:

> Textbooks on ventilation and engineering handbooks devote little or no space to methods of control of industrial dust, and in the technical journals papers on fundamental engineering design of equipment are conspicuous by their absence. In a recent bibliography of the literature on pneumoconiosis less than 1 percent of the articles dealt with the engineering control of the disease. The science of dust control has not developed beyond the stage of trial and error, and the design of structures for the suppression of dust is based almost entirely upon empirical data together with one or two elementary formulas. The latter were derived from the generalized experience in a limited number of industries such as woodworking, where conditions and requirements are not at all like those, for example, in a sand-pulverizing plant. Wide experience and good judgment are essential to the proper use of the scanty information that has been collected and systematized. Without attempting to minimize the importance of experience in engineering design, it is necessary to point out that most of the past experience obtained in the empirical design of dust-control equipment was not evaluated by means of quantitative studies of the actual reduction in dust. Hence, past experience does not necessarily furnish the proper guide for future design. In fact, recent surveys in certain industries, employing modern methods of investigation, have shown that existing equipment is in many cases inadequate.
>
> Dust control, as practised today, is to some extent the offspring of dust collection, but since they are opposite in purpose, the requirements of one are not necessarily like those of the other. Thus, manufacturers of dust collectors may guarantee collection of 99½ percent and in the production of a commercial powder this is entirely satisfactory, but it has no meaning in the performance of dust-control equipment. It is the escaping dust, not that collected, which is important, and guarantees of performance must be based upon permissible amounts of dust at the breathing zone of the workmen and in the "clean" air discharged from the equipment. For example, assume a safe limit of dustiness in the air discharged from a certain plant to be 1 mg per cubic meter or 0.0000013 grain per cubic foot and assume also a dust loading of 30 grains per cubic foot. Under these conditions, which are not abnormal, the efficiency of dust "collection" must be 99.9987 percent! ***.
>
> The systematic correlation of actual results with the details of design, coupled with an understanding of the physical properties of dust and the laws governing its dispersion and behavior in the air, will provide a body of facts upon which to base the engineering design of equipment.

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For those who believe that free silica is the only harmful dust the first step toward dust control obviously would be to establish standards of permissible dustiness--as proposed in the preparation of certain codes for the dusty trades--for dusts containing varying amounts of free silica. According to Hatch (146), the maximum allowable rate of intake or standard of permissible dustiness varies with the physical and chemical nature of the dust and the nature of the exposure. A safe value probably exists for every industrial dust, and workers may be exposed to concentrations below the threshold value for long periods without serious damage to lungs or incapacitation. The object of any dust-control program must be to reduce plant dustiness below this figure. Unfortunately, permissible values have not been generally determined, and an estimate of the health hazard in a particular industry therefore must be based upon a careful interpretation of the complete data obtained through occupational and sanitary analyses and medical examination. However, Hatch (146) states that a standard, such as that tentatively set by the United States Public Health Service (10 to 20 million particles per cubic foot of air for granite dust containing 35 percent free silica), in the absence of definite evidence is perhaps justified, provided the figures are not accepted too dogmatically, as once they have been fixed in official codes they attain a sort of sacredness and are removed or changed only with great difficulty. As knowledge of pneumoconiosis is incomplete and methods of medical diagnosis, as well as the technic of dust analysis, are still in the state of development, standardization as to allowable air dustiness would be unfortunate at the present time. Stratton (261) agrees with Hatch that standards of permissible dustiness are too young at the moment to be legislated into State laws or codes, inasmuch as they could be changed only with extreme difficulty upon collection of more complete data; but the use of such standards by individuals, State authorities, and others as a criterion by which to judge an exposure existing either in an industry or a plant he considers advisable and the use by large groups of industries, authorities, or individual technicians would assist in the collection of more complete data, the review of which would prove or disprove the effectiveness of the standard or its accuracy. Unfortunately the natural causative periods of certain industrial diseases are of such duration that experimental control measures must be extended over years to prove their worth; meanwhile the improved measures based upon the existing standards probably can be accepted generally with advantage.

Since no definite, absolutely reliable standards of allowable dustiness are known obviously the aim in the prevention of dust diseases should be elimination of all dust in the atmosphere where people work. Although this aim possibly cannot be realized completely a sincere and continued attempt to attain it unquestionably should result in a gratifying reduction of the dust hazard in industry.

As stated by Harrington (262), the outstanding remedy for the bad situation (in many localities a most distressing one) with respect to dust disease is education--education of workers in the necessity of taking available precautions; of employers in recognizing the seriousness of the situation and in providing devices and methods to reduce or prevent the incidence of disease and, if necessary, in forcing their adoption on the workers; of doctors in correctly diagnosing disease, giving publicity to its prevalence, seriousness, preventive remedies, etc., and assigning in death certificates dust disease as the cause if such is the case; and of merchants, newspapers, and other influences in the community in trying to prevent the disease rather than to hide its existence.

Instead of recognizing the menace of diseases of various kinds associated with breathing dust and taking advantage of the available methods of combating or preventing them, or at least making a study of the situation with a view to alleviating the harmful conditions and their terrible results, in most instances Harrington (262) finds that--

> There is apparantly a concerted effort to hide the facts and to take as few measures as possible toward elimination of the diseases and of the conditions causing them. Miners, especially metal miners, whose health is most directly affected usually refuse to allow themselves to be physically examined previous to or during employment; they frequently oppose the use of wet drills which probably more than anything else will remedy the dangerous dust condition, and in many instances they destroy or try to make ineffective the water attachments to drills; when water is provided to wet down the dust it is generally not used, except when the mine boss forces the worker to it; and mine-workers only too frequently destroy or partly destroy ventilation equipment installed for their safety, comfort, and health. Mine operators or officials usually deny the existence of miners' consumption or other dust disease among employees, yet frequently some of the mine bosses themselves are afflicted by such disease. Suggestions as to remedial methods or equipment, such as sprinkling or the use of water in drilling or in coal cutting, or the use of currents of fresh air to remove dust, are held to be impracticable or are considered the dream of the theorist, even though these methods or devices are in thoroughly successful use in other mines or in other localities. While sometimes the objection to change is due to disinclination or inability to withstand the probable financial outlay, frequently the main obstacle is the fact that mine officials of reactionary type, usually the oldtimer of years of experience and more or less limited education, hates to do anything that he has not been accustomed to doing and repels the idea that dust is or can be harmful.
>
> In some instances, after the higher officials of mining companies have spent large sums of money to install equipment with a view to combating dust diseases in mines, the mine bosses who actually oversee the mine operations are not in sympathy with the "new-fangled ideas", and they make little or no effort to cause the workers to use the preventive methods; sometimes the bosses are in sympathy with the new devices or methods but have not the will power or the "backbone" to force the mineworker to use the new method or device. Doctors, merchants, engineers, business men in general in the community, even those not directly connected with the mines, who should (and frequently do) realize the gravity of the situation as to disease among mineworkers and their families (as tuberculosis frequently intervenes), from motives of self-interest remain quiet. Death certificates of victims of dust diseases are made out as heart disease, or Bright's disease, or almost anything but miners' consumption or bronchitis, and newspaper reports indicate that death was due to a "lingering illness."

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Cummins also called attention to the attitude toward dust-preventive measures taken by some miners, according to a statement by the Colliery Guardian (263):

> Dr. Cummins also had hinted at a very important aspect of dust prevention when he stated that he had heard that the miner "will not wear a respirator of any sort.". This was partly true. He had even known of cases where the expensive dust receivers had been mishandled and spoiled and more frequently cases where men found it too much trouble to use them. If they acquiesced and allowed this attitude to become a common one the whole campaign against dust would be futile. He would go so far as to say that a second or third offense of this kind should entail dismissal and forfeiture of right to compensation. At the present time, especially, the colliery companies should not be asked to spend more unless every effort were made to insure a full return for their expenditure.

In an article on certain of the legal aspects of silicosis Farrell (264) made the following statement:

> Because sickness from dust exposure is commonly referred to as silicosis, there are many industries having a dust hazard that are not cognizant of the fact and remain in ignorance of it until they are greeted with a summons. Subsequent investigation and a conference with counsel bring home the fact that there is some merit to the suit, and that there is also an industry hazard that is going to prove expensive. The check-up will also often reveal, where there is insurance, that because this hazard was not known to exist there is no coverage for it and that the problem is thus one which the company's lawyers will have to cope with and which the company will have to pay for.

Willson (265) calls attention to the difficult if not alarming position in which employers in dusty trades now find themselves; not having been fully warned or informed until lately of the special dangers of certain dusts, they have exercised merely general care in dust prevention. Anyone not familiar with the exact situation in industry may wonder why employers did not attempt years ago to control the silica-dust hazard. Willson (265) thinks that most employers undoubtedly would have done so if they had been aware of the danger; unfortunately the subject, although under investigation and fairly well understood in scientific circles, was largely unknown to industry, and dust to employers was merely "dust", one kind being thought to be as dangerous as another. According to Willson--

> Most well-intentioned employers may be said to have used "reasonable care" in past years, and this "reasonable care", considering their lack of knowledge, is now their best defense in the damage suits just referred to. However, from now on, with the spread of common, or at least available, knowledge of the peculiar danger of certain dusts, only "special care" will safeguard the interests of employer and workman alike.

Let us now consider what present steps will constitute "special care" where dangerous or poisonous dusts are present: in other words, what shop precautions are now known to be absolutely necessary, based on the knowledge of silicosis just made available to us.

Employers in industries where free silica is present in the atmosphere should constantly be alert and watchful, discounting to the fullest extent every possibility of danger. Employers should not conclude that they have entirely eliminated danger of silicosis, or of any type of pneumonoconiosis, simply because the air is seemingly free from dust. It should be borne in mind that the particles which do the most harm are invisible and that they remain long in suspension in the air. It has been estimated that dust particles 1 micron in diameter require 8 hours to fall 6 feet in still air and that even larger particles, 5 microns in diameter, require nearly an hour to fall to the floor from the height of a man. Particles remaining so long in suspension in room atmosphere continue the danger throughout the entire working day; hence the urgency of postponing sweeping and dusting until work for the day has ceased. Often dust is thrown back into the air during these operations. Furthermore, dust of dangerous character may be so extremely fine in grain as never to settle at all but remain in suspension indefinitely.***.

Getting workmen to wear safety devices requires the same mental attitude on the part of the management that a good salesman must have when he goes out to capture a difficult new account. If the management is not convinced that protective devices must be employed at all times, and if they, in turn, cannot convince their shop superintendents and foremen that such devices are necessary, then they cannot but blame themselves if workmen fail to manifest a good spirit toward self-protection. For psychological as well as for protective reasons, shop superintendents, as well as foremen, when approaching dusty operations should invariably wear their respirators, and even visitors to plants should not be permitted to enter dusty departments without wearing respirators. In this way workmen can finally be convinced that the management truly believes in full-time protection. For best results every one concerned should be willing to live up to the rules of the shop, without exception. In this work any weakening on the part of the management is fatal.

The most erroneous and expensive policy any employer can adopt is to minimize to his workmen the dangers of free silica dust; no true observance of dust protection can be expected from the workman unless he is fully acquainted with the dangers of his occupation.

It cannot be assumed that workmen in our American factories are so unintelligent as to wish to ignore dangers about which they have been fully informed. Rather they, like the rest of us, are apt to scoff at occasional warnings, preferring to doubt that danger exists. It is essential, then, that the management should know the truth first of all. Supervisors should be told the whole story, and workmen severally and individually, in season and out of season, week in and week out, should be educated, warned, and even cajoled into full observance of the rules. Anything short of this will never bring about a decrease in silicosis where free silica is handled. Unless this end is attained the burden of liability expense, whether determined by civil suit or by workmen's compensation laws, will grow progressively heavier as statistics accumulate.

Where this has not already been done it would be wise, as an additional precaution, to organize shop committees in dusty plants. These committees, selected from management, supervision, and common labor, should make periodic inspections of their respective plants and draw up recommendations for improvement in equipment and shop maintenance. Recommendations made by shop committees so constituted are generally more convincing to workmen than orders issued directly from headquarters, and considering the situation as to liability, no step, however radical, is to be overlooked or neglected. Liability cannot be lessened by having workmen sign waivers or by any other means than protection and prevention.

In an article published in the June 1934 issue of Industrial Medicine McCann (266), professor of medicine in the University of Rochester, described the hurricanelike suddenness with which a deluge of common-law suits for negligence fell upon various industrial employers in Rochester, N.Y. In the beginning these suits alleged that the injury was due to silicosis; the indefiniteness of the diagnosis of silicosis is shown by the results of the investigation by the University of Rochester for the industries concerned. It was learned that quite a number of different diseases produce changes in the lungs which in X-ray pictures resemble closely the early stages of silicosis. The use of this information by the defense led to broader claims for injury— "silicosis became pneumoconiosis, and this in turn became fibrosis and disease of both lungs and upper respiratory passages due to inhalation of dust." Although designating the prosecution of such claims as a "rapidly growing racket", McCann (266) stated:

> Preliminary dust counts showed that in a number of plants dangerous quantitites of dust were in the air, in spite of the fact that operations were proceeding at a mere fraction of normal.
>
> The results of the X-ray survey so far have likewise been disturbing.***.
>
> I feel sure that the cost of eliminating dust will be far less than the cost of insuring against the hazards of dust. Money should be invested now in research in dust prevention and dust removal. I cannot believe that inventive genius will fail to respond to this dire necessity. Different industries will have to solve this problem in different ways, but no one can doubt that ways can and will be found and that they will be less expensive than paying for lawsuits or awards.

Dust Control in the Mining Industry

The first systematic study of silicosis among miners was undertaken in South Africa, and methods of control of the dust hazard in the mines of that country have been an example for other mining districts of the world. The awakening to the seriousness of the hazard in the mines of South Africa came in 1901, when a report by the government mining engineer disclosed an annual death rate of 73 per 1,000 among the miners (81). The report of the first Miners' Phthisis Commission, issued in 1903, made certain general recommendations regarding dust prevention--particularly in development work--ventilation, underground sanitation, and provision of "change houses" for miners. A phrase in the Report of the Transvaal Medical Society (81), "dry mining must as far as practicable become wet mining", reflected contemporary opinion and indicated the main direction of dust-prevention measures on the Rand to the present time.

As a result of the Commission's work (81), regulations issued in 1904 and 1905 required that sprays or jets be used with machine drills, that broken ground be damped in development places, and that blasting operations be arranged to avoid exposure to dust; return to working places was prohibited after blasting until the air was clear, and efficient ventilation was to be provided.

Unfortunately no effective means of enforcing these measures were prescribed, and the inborn conservatism of the miners, who have more or less universally disliked innovations in traditional ways of working, did not help matters. Unquestionably conditions were much improved but not enough to produce very substantial results. The idea persisted that the main cause of the trouble was rock drilling with machines and that rock-drill machineworkers in mines were virtually the only sufferers; the very dangerous conditions produced by the widespread dissemination of blasting dust received inadequate attention.

In 1907 a second Commission was appointed by the Government of the Transvaal. Medical evidence submitted to it by Macaulay and Irvine (81) indicated that the local mortality from phthisis during 1905-07 had been approximately six times higher among underground workers than among other males on the Rand. A revised code of mining regulations based upon recommendations of the Commission was promulgated in 1911, instituting many improvements. Chief of these were the introduction of qualitative tests of ventilation and the requirement of mechanical appliances where natural ventilation was inadequate. As before, the use of water jet or spray was required in machine-drilling, and the responsibility of the manager to maintain an adequate and constant supply of clean water for use of these appliances and for damping down working faces and broken rock in ends and stopes was tightened. Responsibility was placed on the sectional officials to insure proper observance of preventive regulations. The result was that the use of water for allaying dust underground became much more general. In 1913 additional provisions introduced into the existing regulation required that an adequate supply of water be provided throughout each mine by a system of pipes. This cardinal requirement led to much greater efficiency and uniformity in the provision of water for use with sprays and jets, for water blasts, and for wetting working places and broken ground.

Regular determinations of the dust in mine air were begun by one mining group in 1911, and the first systematic dust survey of all mines was conducted by the Prevention Committee in 1913-14 (81).

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The February 24, 1934, issue of the South African Mining and Engineering Journal (269) summarizes the dust-reduction methods used in South African mines as follows:

1. Wet drilling.- Water is kept in the hole throughout the whole period of drilling, whether by hand or machine. This has been compulsory for the past 12 years.

2. Water-spraying (by water blast).- This is done especially after blasting; all likely dust-making surfaces are kept wet.

3. Filtration.- Flannel filters are used at the ore bins (on the crushers) and in other places. These need changing every 2 hours in some cases.

4. Time.- An adequate period is enforced between blasting and return to the working face; this allows much of the dust to settle.

5. Sampling.- The air is systematically sampled by the konimeter, its dust content examined and recorded.

6. Ventilation.- A continuous supply of pure (filtered and cooled where necessary) air is pumped to all working places underground and arrangements made for the proper removal of foul air.

7. Wearing of masks.- Occasionally individual officials wear a mask containing cotton wool or gauze.

The following suggestions were made to further diminish the dust danger in South African mines (267):

1. Limitation of drilling to those parts of the face which contain least sericite (the fibrous death-dealing mineral).

2. Comparison of results under similar conditions of wet and dry mining.

3. Discovery of explosives that blast out lumps of rock, rather tha shatter it into small fragments and manufacture dust.

4. Removal of more dust by way of the upcast ventilating shaft.

5. Addition of proportion of soap, naphthaline, or other substance to water for washing down after blasting in order to increase its dust-catching powers.

6. Development of a new technic for konimeters (dust measuring instrument) so that the proportions of sericite in mine air can be ascertained.

7. Increase in the number and efficiency of dust traps and filters.

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8. Provision of suitable light masks to which air free from dust, oil, and poisonous gases can be supplied by means of flexible long tubes to the air-pressure pipes now used for pneumatic drills or from light portable cylinders containing compressed air, so that underground air is never inhaled.

The following possible lines of attack have also been mentioned (267):

1. The discovery of a solvent for sericite.

2. The use of an oily solution for the inside of the nose with a strong, simple application that can be carried and frequently used.

3. The daily removal of all dust (by vacuum cleaners) from clothing worn underground.

4. The use of snuff for compulsory sneezing.

The statement has been made (155) that preventive methods, such as wet drilling and water-spraying, have not been successful in depositing the finest and most dangerous dust and in preventing the incidence of silicosis. It has been suggested (155) that the problem of prevention in the South African gold mines could be solved by using an apparatus (not a respirator of usual type) that would enable the miners to breathe directly the fresh uncontaminated surface atmosphere already available through the air-pressure pipes supplying the pneumatic drills.

According to the Colliery Guardian (268), water at best is a poor layer of the fine dust which is most harmful, whether silica or chiefly sericite; but since water has been used konimeter estimates show that the dust in mine air has been reduced considerably, and the rate of production of silicosis has also decreased.

The South African Mining and Engineering Journal (269) states that gratifying progress continues to be made by the Chamber of Mines in its campaign for the prevention of phthisis through the laying of ordinary dust. Exhaustive tabulations show that today the standard of purity in underground air continues to rise. Between 1933 and 1934 an improvement of 1 mg per cubic meter was reported. An expert said that "actually the standard of dust purity at the bottom of many of our mine shafts has been shown to be substantially higher than that of Johannesburg streets on a windy day." If silicosis is caused by the inhalation of dust the removal of dust will remove the cause, which means, according to Bateman (270), ventilation and lots of it and, where possible, the wetting down of dusty places. He states that ventilation and water will remove the visible dust from the air, but it is not the visible dust that causes the damage but the dust that ranges between ½ and 5 microns, which is very difficult to remove; the quantity in the air can be determined only by some method of sampling. However, he considers it a mistake to have either the type of sampling apparatus or the permissible dust count defined by law; "this," he says, "may be all right on the Rand in South Africa where conditions are more or less standard, but it is not advisable in the United States or Canada where conditions vary so greatly."

Sources of Dusts in Mine Air

The main sources of dust in metal-mine air in the order of importance are (262): Dry drilling of holes for blasting (dry drilling of holes pointed upward, especially from about 70° vertical, is, in general, the worst); blasting; shoveling or "mucking" very fine dry material at the working face, which is usually poorly ventilated; loading cars from chutes; dumping loaded cars into chutes; and timbering. Dry crushing and other occupations in metal-mine mills are also dangerously dusty. One such mill in Nevada caused so many fatalities that the death certificates of the victims showed the cause of death as dust from this mill, the disease being called by the name of the mill.

The most dangerously dusty occupation in coal mines (262) is the cutting of dry coal by mining machines. Electrical cutting machines usually produce more dust than compressed-air machines. Undercutting machines send enormous amounts of very fine dust into the surrounding air; shearing, centercutting, or overcutting machines produce even more dust than undercutting machines. Blasting throws large quantities of very fine dust into the air; shoveling dry coal into cars and loading dry coal into cars from chutes are also very dusty coal-mining occupations, particularly when pillars are being extracted. Some coal miners drill overhead holes into shale or other rock roof to prepare for "brushing" shots to increase the height of low coal workings; when these holes are drilled dry by breast or rachet augers and the cuttings allowed to fall through the air past the face of the driller the danger from dust inhalation is great; similar use of dry jackhammer-type compressed-air drills either in coal or in the rock, shale, or clay of the roof or floor gives such dusty air that the driller and all persons in his immediate vicinity inhale enormous quantities of very fine, more or less insoluble dust. In dry coal-mine workings enormous amounts of a very finely divided mixture of coal and rock or shale dust frequently collect on haulage or travel roads and present a serious hazard if the circulation of air is sluggish or practically nonexistent.

There is probably not one dry mine in the United States, coal or metal (262), where the average air dustiness of working places is as low as 5 mg per cubic meter of air (the South African standard) or 10 mg per cubic meter of air (the standard set by Higgins and Lanza in their study of miners' consumption in the Joplin (Mo.) district in 1915). In general, the average air dustiness of working places in dry metal mines in the United States (262) is above 20 mg per cubic meter of air and in many, above 50. Shoveling coal in one mine in a confined, poorly ventilated very dry place gave approximately 8 billion particles per cubic meter of air; numerous places in the same mine where men were shoveling gave 1 to 5 billion particles per cubic meter of air. In another coal mine where an undercutting machine was cutting in coal without the use of water on the cutting chain the air breathed by the workers contained nearly 5 billion particles per cubic meter of air; over 4 billion of these were less than 10 microns in size, and hence were probably breathed directly into the lungs. In these instances much of the 8-hour shift was spent in breathing such air, and it is not surprising that physical examination showed many cases of miners' consumption or so-called "asthma" among these coal miners (262).

The following conclusions were reached by the United States Bureau of ines (271) from a study of sources of dust in 15 representative coal mines n 6 coal-mining States:

1. Jackhammer-drilling produced the greatest concentrations of dust of any of the mine operations, 10 times as much as any of the others, and the other dust-producing operations arranged in decreasing order of concentration were electric drilling, undercutting coal by dry methods, auger-drilling by hand, loading coal, undercutting coal with the application of water on cutter bar of mining machines, simultaneous pick-mining and loading coal, loading rock, haulage, and finally, pick-mining.

2. The largest total amount of dust was raised by dry undercutting.

3. Undercutting coal without the use of water on the cutter bar raised the greatest concentration of dust of any of the common mine operations; loading coal ranked next and haulage last.

The United States Public Health Service reported (180) the following esults of 80 dust determinations--60 underground and 20 in the breaker--made t an anthracite mine in the United States in 1926:

The miners and mine laborers, who made up two thirds of the total force employed in the anthracite mine, were exposed at times to an exceptionally high concentration of dust, namely, almost 1 billion particles per cubic foot of air. The average, however, which takes into account the time spent under different conditions of dustiness, was much less, being 124 million particles per cubic foot of air.

In addition to the miners and their helpers, two other groups of underground workers were exposed to a relatively large amount of dust: (a) The rockworkers and (b) the runners and drivers, who have to enter the miners' workplaces at times when the air is particularly dusty. Considering the time spent in the dusty and relatively nondusty parts of the mine, one may estimate that the average exposure of the runners and drivers was about 36 million particles of dust per cubic foot of air. The remainder of the underground workers were exposed to a relatively small quantity of dust. Aboveground it was found that the men in certain occupations, namely, the coal dumpers, jigmen, and slate pickers, were exposed to nearly as much dust as the coal miners. At the breaker the dust is practically the same as that in the mines.

The rockworkers are the only ones exposed to a dust containing a high percentage of quartz (31 percent). Since the average concentration of dust was 82 million particles per cubic foot of air, it is obvious on the basis of previous experience that these workers have a severe hazard. Small numbers and lack of occupational continuity made specific study of this group impossible.

In addition to counting the dust produced by various mining operations, the extent of the hazard may be determined by physical examination of the mineworkers and correlation of the results with their occupational history. The results of the study made at Picher, Okla. (89), showed the following connection between dust exposure (occupation) and dust disease:

> All examined were divided into two groups: (1) Those exposed to large amounts of dust (those employed at the face) and (2) those exposed to relatively small amounts (those away from the face). Dust investigations of the mines show that the bulk of dust is raised at the face.
>
> In the order of exposure to the dust hazard, the men at the face include shovelers' helpers, shovelers, drill helpers, machinemen, trackmen, roof trimmers, powdermen, shovel bosses, and ground bosses. This group included 3,051 men (61.1 percent of the 4,992 men). Of the 3,051 men 296 (5.9 percent) were not required to be at the face all of the time. These were ground bosses, roof trimmers, and trackmen. A tabulation of the men working at the face, including the 3 groups last named, shows that 38 percent have silicosis, silicosis with tuberculosis, or tuberculosis uncomplicated.
>
> The men working away from the face include screenmen, mule drivers, hookers, hoistmen, bumpers, trammers, roustabouts, ropemen, pumpmen, electricians, safety engineers, superintendents, and millmen. At the time of the examinations 1,941 men (38.9 percent of the total 4,992) were employed in these occupations. Of this second group 24.9 percent had silicosis, silicosis with tuberculosis, or tuberculosis uncomplicated, as compared with 38 percent for the first group.
>
> The group of men not employed at the face includes the hoistmen, who are, however, exposed to considerable dust arising from the arrangement of hoisting machinery. There were 270 hoistmen (5.4 percent of the 4,992); of these 101 (37.4 percent) had silicosis or tuberculosis or both diseases. Excluding hoistmen, the men employed away from the face showed only 19.7 percent with silicosis or tuberculosis or both. Many in this group are old miners who, because of their experience, are placed at this work. Some are physically unable to do facework and are forced to less remunerative positions away from the face.
>
> A study of the past occupations of the second group shows that 274 had worked at the face 1 to 30 years, an average of 9.9 years for the group. If these men, who had formerly worked at the face, are considered as really belonging in the first group the data show that 43 percent of the facemen ultimately contracted silicosis, as compared with 5.6 percent of the men who had worked the entire time away from the face (exclusive of hoistmen). A study of the occupations of the men before they began work in metal mines shows that 0.8 percent were employed in dusty occupations, such as tool-dressing, concrete-dressing, ore-loading, or foundrywork. The silicotic miners who worked away from the face had been employed in the mines an average of 19.1 years; those with silicosis and tuberculosis, 15.5 years; and those with tuberculosis (not complicated with silicosis), 13 years.

Fifty-two men in the group who had not worked at the face had doubtful histories; although they are included in the tabulation and account for approximately half of the group with silicosis and tuberculosis they are believed to have been facemen formerly. With these men included, the data show that the men working at the face are approximately eight times more liable to contract silicosis than those working away from the face.

A study of the control of drill dust in the mining industry in Germany (272) revealed that the dust burden and danger is not so great in the majority of German mines as in some other countries. Relatively the greatest dust hazard is in machine-drilling with compressed air in metal mines and in exploration and preparatory work in dry, hard country rock of the hard-coal mines, because the miner must breathe directly large amounts of injurious dust at the place of origin. The report (272) states that the dust caused by drilling is thrown into the air and dispersed by the circulation of the air and the air movement caused by the operations and by the exhaust from the compressed-air apparatus. There is an extensive sifting of the rock dust in moving air according to particle size or, more exactly, according to uniformity. The greatest part of the drill dust from the ordinary spiral or twist drill issues quietly from the mouth of the drillhole and runs to the ground in a moderately coarse stream; this stream of coarse material comprises more than 90 percent by weight of the entire drill dust, falls without developing much dust, and causes virtually no trouble for the worker. Part of the drill dust measurable by weight, however, is circulated immediately through the atmosphere by moving air and carried a short distance but loses its cloud-forming ability and soon falls, according to the velocity of the air stream, several meters from the drillhole. The medium-fine drill dust floats in the air as actual dust but on account of its inability to remain in suspension is not carried into the other mining rooms; it is seen as a thick dust cloud before very heavily coated places, settles in a crust on rock piles, or is deposited on the floor and timbers and covers the tools and bodies of the workers. This dust is especially severe at the mine face and by irritation of the mucous membranes of the eyes and the respiratory organs causes catarrhal inflammation, coughing, and colds. However, it is not the worst enemy. Really dangerous are the weighable amounts of the finest dust, which rises from the drillhole at the face as fine smoke and remains in suspension for hours. This almost imperceptible dust cloud, often forming considerably less than 10 percent of the total dust originated by drilling, diffuses even in motionless mine air into the general air stream and is carried through the entire mine.

Methods of Controlling Dust Production in Mines

After many years of observation Harrington (273) has reached the following conclusions regarding remedial dust measures for metal mines:

1. In mining it appears that ventilation, fire protection and prevention, health, safety, and efficiency are very closely interlocked.

2. There is at least equal reason for providing adequate ventilation for most metal mines as for providing ventilation for coal mines.

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3. Metal mines rarely, if ever, make provision for ventilation until forced to do so by some untoward condition or occurrence; coal mines, on the other hand, almost universally provide for ventilation.

4. Efficient ventilation of metal mines consists in supplying at all times such volume of circulating air at places where men work as will enable the worker to exert himself in comfort at maximum physical capacity without endangering his health.

5. Many, probably most, operating officials of metal mines are ignorant of the principles of air circulation; this is true of those technically educated as well as of those without technical training.

6. Workers in metal mines, including shift and other bosses, should be educated to respect ventilating devices, such as doors, regulators, overcasts, brattices, fans, etc., as coal miners do and to become as familiar with those devices as coal miners are. Many present-day reactionary metal miners and bosses consider ventilation a useless fad and obstruct rather than aid ventilation improvements.

7. Ventilation should be under definite, constant supervision, and preferably the person in charge should report to the highest officials, as many local officials in metal mines are not in sympathy with ventilation betterments.

8. Each mine should be ventilated wholly within itself; interventilation of mines is likely to be dangerous, inefficient, and unsatisfactory.

9. Workers in many metal mines are much less healthy than workers in coal mines, due largely to the superior ventilation of the collieries.

10. Miners' consumption, the scourge of metal miners, is caused primarily by breathing very fine particles of certain mineral dusts and especially of siliceous dust. Over 50 percent of mineral-producing mines are working in more or less siliceous material and, through lack of ventilation, are giving this dangerous dust maximum opportunity to exercise its harmfulness.

11. The best remedy for the dust menace in mines, other than preventing its formation, is the universal coursing of currents of air to remove the dust, as it has been proved that the very fine, most dangerous dust in metal mines remains suspended in still air several hours.

12. Metal-mine dust, acting through miners' consumption, lead poisoning, bronchitis, etc., is the chief instrumentality in causing perhaps more deaths annually among the approximately 200,000 metal miners in North America than coal dust causes to the approximately 700,000 coal miners through explosions.

13. It is fairly well-established that miners' consumption is caused chiefly by siliceous dust, but it is probable that any kind of dust in large quantities in finely divided form in mine air will prove harmful to workers

ltimately. Investigations in metal mines of the United States indicate hat the air of mines so far studied is from 7 to 40 times as dusty as in outh African gold mines.

14. Intake air of metal mines is frequently rendered dusty by having a rusher house or other dust producer near the collar of the intake air haft or by having ore skips or cars or ore-dumping places in intake air assages without the slightest attempt to allay the dust produced or to revent its entering the mine.

15. The dustiest, most unhealthful occupation underground is dry drilling, nd the average dust content of air in places where this work is done in 5 arge mines in various parts of the United States was 205 mg per cubic eter of air; yet for similar work in South African mines, but using available recautions against dust formation, the dust content of air is said to be ess than 5 mg per cubic meter of air.

16. Although there are regulations in many of the mines of the United tates to prevent dust formation in drilling these regulations are not al- ays lived up to. Miners, although recognizing the danger from dust, often refer to take the risk rather than endure the slight discomfort of extra rouble of using the precautionary methods or devices; and mine and State fficials appear to feel that, unless the miner will willingly aid in pro- ecting himself, they cannot force him to protect his own health and inci- entally that of his family. Dust-prevention devices of proved success, uch as present-day self-rotating wet stopers, should entirely supplant ry drills, and their use should be enforced upon both miners and operators n metal mines, as there is absolutely no valid excuse for dry drilling in resent-day metal mining except in a very few instances. To date, no orkable device is available for removing dust in dry drilling in under- round mines.

17. Spraying devices available to reduce dust while drilling may be ffective if used intelligently; on the other hand, they may even intensify he air dustiness if used without intelligence and unfortunately, the latter s generally the case. Efficient water drills are now available for all urposes in metal mining (including efficient wet stopers for upper holes), nd dry drilling should be prohibited.

18. Some metal mines with high dust production under certain conditions t working faces have comparatively low dust content of the air in these laces at other times and have low average dust content of all places due efficiency of ventilating currents, especially at working places. Sig- ificantly, these mines appear to be singularly free of miner's consumption other diseases, yet the employees work at top speed and the material andled is highly siliceous.

19. The use of poorly placed compressed-air hose blowers at working aces frequently intensifies air dustiness by allowing high-velocity com- ressed-air streams to pass through dry, loose, finely divided ore or other aterial being drilled, shoveled, or otherwise handled, and thus forcing rkers to breathe this air highly impregnated with dangerous fine dust.

20. While finely divided dust in mines is probably the chief cause of miners' consumption, it is now recognized that there may be other factors of almost equal influence, such as high temperatures and humidities, harmful gases, and lack of air movement; all of these defects are readily remedied by ventilation.

The following comparison of mining practice in the United States with that in South Africa is interesting (262). In the South African mines on the Rand about the same number of miners are employed as in all of the metal mines of the United States, and the problem of dust disease is not "side-stepped" as it is and has been in the United States. About 30 or 35 years ago a very complete health study was made, revealing the extreme seriousness of dust disease among the workers and resulting in the adoption of drastic laws and regulations, which apparently are rigidly enforced and which are said to have resulted in a marked decrease in the incidence of the disease and of the death rate from it. Mines with 1,000 men or more underground must have employees especially detailed on dust and ventilation work, whereas only a few of the metal mines or tunnels in the United States even consider dust or ventilation. South African mines must have running water, under a minimum pressure of 30 pounds a square inch in not less than 1-inch pipe within 50 feet of working places; very few of the metal mines of this country, on the other hand, have water available near working faces. South African mines must also have water blasts and sprays at or near all working faces; few, if any, American metal mines have them. All drilling in South Africa must be done with drills through which water flows into the hole to prevent formation of dust; many miners and mine officials of this country insist that "it can't be done", especially in the drilling of upper holes. In South Africa all blasting must be done after the men are out of the mine, the region where blasting is done must be wet down thoroughly both before and after blasting, and men must not enter until 30 minutes have elapsed after blasting; in most mines of the United States blasting may be done at any time--in general, no provision is made to wet places at any time before or after blasting, and men return to blasted places whenever they are ready. South African mine travelways and ore or rock piles must be sprinkled enough to prevent dust; very few metal mines or tunneling operations in the United States sprinkle, and most of the operators say sprinkling is impracticable. In South African mines old workings must be closed, air currents must be split, air dustiness and chemical composition must be determined periodically by sampling and analysis, shift bosses must take daily record of the use of water against dust, and numerous other preventive regulations practically unknown in the United States are in effect and said to be strictly enforced.

An examination of the amount of air driven through coal mines in France and the dust content of the air as it emerges from the pits indicates that ventilation provides excellent prophylaxis against pneumoconiosis (274). The dust is composed of fine particles of coal, silicates, and crystalline silica; the silica constitutes 10 to 60 percent of the total. The density in the workings is seldom less than 6 mg per cubic meter and may be as much as 500 mg. Even the less favored miners get 100 liters of fresh air a second.

Education is badly needed among coal miners (262). The coal-mining public, instead of "standing pat" and referring to out-of-date and misleading foreign statistics that coal dust is harmless to health or is even healthful, should make an impartial but strict study of dust conditions in coal mines (anthracite, bituminous, and lignite), paying particular attention to X-ray examination of the chest; coal-camp doctors who have direct knowledge of the harmfulness of coal dust to underground workers, especially those working on mining machines, should write technical articles describing the situation; and State and Federal authorities should cooperate in making studies and publishing results as to the health situation of workers in dusty places in coal mines. The introduction of rock dust into coal mines to prevent or limit explosions is a long step toward coal-mine safety and need not introduce any additional health hazard into coal mines. If the face regions of dry coal mines are kept well-watered to a distance of 40 or 50 feet from the face and rock-dusting is maintained in all other accessible parts of the mine there will be little or no health or explosion hazard. Water should be piped to all dry faces in coal mines and used on the cutting chain while undercutting, overcutting, centercutting, or shearing; faceworkers should sprinkle the face region within 40 or 50 feet of the face (ribs, roof, floor, and coal pile) at least 3 times daily, as well as sprinkle (not soak) the top of all loaded cars before they leave the face.

Water.- The British Coal Mines Act of 1911 (275) requires that "a drill worked by mechanical power shall not be used for drilling in ganister, hard sandstone, or other highly siliceous rock, the dust from which is liable to give rise to fibroid phthisis, unless a water jet or spray or other means equally efficient is used to prevent the escape of dust into the air." The minutes of one of the meetings of the Health Advisory Committee of the Mines Department stated that--

> In many cases no attempt is made to prevent the dust emitted from rock drills entering the air of the mine. The water sprays which are used in some cases are inefficient, as the volume of water is small and does not wet the smallest and most injurious particles of dust. The men strongly object to the efficient use of water through hollow drills on grounds which are intelligible. The results are fairly good when new drills are used, but after a short time there seems to be commonly a leakage of air into the drill, with consequent inefficiency. There are, of course, some places where water drills are used effectively, but the Committee are of opinion that another means of trapping the dust is required.

At the International Silicosis Conference in 1930 (276) it was pointed ut that water is used in three different ways on the Witwatersrand: To revent the formation of dust during the drilling of holes in blasting and he handling of broken rock; for wetting all surfaces to secure a "fly-paper" ffect in retaining dust settling on those surfaces; and for spraying into he air to allay dust already formed. It was generally agreed that water applied t the site of percussion or fracture tends to minimize the formation of dust, ut attention was drawn to the fact that in several operations--rock-drilling, tonecutting, grinding, etc.--sparks accompanied by dust escape even when the

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surfaces concerned are actually under a film of water. The view was expressed that, since there is no particular reason why dust particles under 3 microns in size should settle on the roof and sides of working places inasmuch as they settle on the floor only after many hours, the value of these wetted surfaces as dustcatchers probably is small. It was pointed out that the dust particles with which the Conference was concerned are of the same order in size as microorganisms and that no one would expect to catch microorganisms by means of a spray. The consensus of opinion was that as sprays are of little value for removing fine dust from the air and that since a humid atmosphere and the presence of droplets had been shown experimentally to increase the risk of various infections their use should be restricted.

Some of the authorities quoted state that water does not remove all the dust from the air. According to Cummings (277) water curtains (water sprays), applied under favorable circumstances have reduced dust concentration 65 percent in contaminated air to which workers have been exposed. He states that "good ventilation, the spraying of water in air passages and upon exposed surfaces, the delaying of dust-producing blasting until the end of the working shift, and the use of respirators in hazardous atmospheres have proved effective."

The following methods for the elimination of drill dust were submitted during a "prize contest" in Germany (272): Prevention of formation of dry drill dust by adding water through the drillhammer and hollow chisel, application of water through the water head and hollow chisel, and application of water through the flush-water pipes beside the drill; removal of dust issuing from the drillhole by sprinkling the dust with water, combining dust with foam, removal of dust by dry absorption, removal of dust by suction, and deflection of the air coming from the drillhammer; removal of air floating about the face; prevention of entrance of dust into the driller by dust masks. The aim of the "prize contest" to find a method of removing the underground hazard from dust caused by drilling was not entirely attained, as a practical apparatus satisfactory under all conditions was not found.

After making a large number of tests when drilling with waterfed drills or with water sprays in operation and obtaining dust concentrations varying between 1,000 and 3,000 particles per cubic centimeter ranging from 0.5 to 10 microns in diameter, Hay (255) advises that before deciding on the use of water as a dust-preventive measure when drilling rock, careful tests should be made with a konimeter to determine whether the fine dust particles are suppressed. He brings out the further important point that a blunt drill steel, due to its pounding or pulverizing action, produces a very much greater amount of fine, dangerous dust than a sharp one; therefore, from the safety standpoint sharp drills only should be used.

Dust traps.- After working 3 years the Safety in Mines Research Board of Great Britain (255) produced an appliance which is claimed effectively to prevent the dissemination into the atmosphere of the dust produced by drilling in rock with a pneumatic percussive drill. For want of a better name this device was called a "dust trap"; it functions somewhat similar to the domestic vacuum cleaner, except that the negative pressure or suction is produced by a compressed-air-operated ejector of the venturi type.

The appliance is a telescopic standard of light steel tubing, which can be set vertically or horizontally; to this standard is fitted an adjustable right-angle bracket, which supports a short length of metal tube in which is fitted the air ejector or suction producer. At one end of this suction tube is a rubber hood with two holes, one of which connects with the suction tube and the other for the insertion of the drill steel. The filtering device is fitted at the opposite or delivery end of the suction tube. The dust-laden air is filtered through a fine-quality, closely woven flannel. The fabric itself is of very limited use as a filter for fine dust, but the layer of fine dust which becomes impacted or enmeshed in the nap of the material forms a tortuous path for the fine dust particles and restricts their passage through the filter which retains them and allows only relatively clean air to escape. The filter, in the form of a bag, is provided with an orifice at the top, forming the inlet, and an outlet at the bottom for the discharge of the trapped dust; the outlet is closed by a strong steel clip. To operate the dust trap, the telescopic standard is set up and the suction tube adjusted so that the rubber hood covers the place where the hole is to be drilled. The compressed air is then turned onto the ejector, the drill steel is inserted through the hole provided in the hood, and drilling proceeds. This appliance was officially approved for use underground after rigorous tests under practical working conditions.

Several similar dust traps have been developed and are described by Hay (255) as follows:

> "Sgnonina" dust trap.- A later type of dust trap is that known as the "Sgnonina." This is a very compact, self-contained appliance. It functions in a similar manner to the one just described, but, in this instance, the apparatus is secured in position on the rock face by means of a small expanding steel mandrel to which is attached an adjustable arm which carries the dust trap proper. For fitting in position, a hole 1 inch in diameter and 2 inches deep is first drilled in the rock. The expanding mandrel is inserted into this hole and locked into position and the rubber-suction hood adjusted to the required position on the rock face. The drill steel is next inserted through the hood and drilling proceeded with, the trapped dust being retained in a filter bag similar to the one already described.
>
> "Trewill" dust trap.- A further dust trap is that known as the "Trewill", which is the invention of a colliery mechanic. This is also a compact and efficient device. It is somewhat similar to the "Sgnonina", but has the advantage that an auxiliary hole is not required to secure the appliance in position. The suction hood is provided with a pair of strong steel jaws in the form of "duckbills" which are expanded in the collar of the hole by means of a large screw nut which is tightened with a special spanner.
>
> "N.A." dust trap.- A still later type of trap is that known as the "N.A." invented by a colliery manager in South Wales. This device is extremely simple in design and operation. It comprises a T-piece of which one arm is in the form of a coned member. For operating this dust

trap ~~a~~ starter hole is first drilled to a depth of about 4 inches, and while this is being done the suction hood of the trap is held in position by hand against the rock face. The cone-shaped member is then inserted into the collar of the borehole and hammered home. The drill steel then passes through the coned member, and boring proceeds in the usual manner.

"Improved Hay" dust trap.- Some 2 years ago the author evolved a new design of dust trap which is officially termed "The Improved Hay." The general principle of this trap is exactly the same as those described but so designed that the suction hood and the filtering appliance form 2 separate and distinct units, being connected together by means of a 15-foot length of light nonkinking rubber-and-canvas hose. The suction hood is secured in position on the rock face by expanding 2 light steel tongues in the collar of the borehole against the tension of 2 spiral springs, by means of a simple cam and lever. The filtering appliance, with which is embodied the suction-producing device, comprises a filtering medium of imitation moleskin fabric in the form of a cylinder. This fabric filter is enclosed in a perforated steel container to protect it against damage. At the bottom of the container is arranged a removable receptacle for holding the trapped dust.

A more recent development of this trap is that the filter device has been redesigned with a view to reducing the size and weight of the appliance. This has been obtained by convoluting or "zigzagging" the filtering area into a much smaller space. It is considered that the considerable reduction in size of the apparatus will enhance its use in difficult and confined places underground.

"Barkston" dust trap.- Another useful trap is the "Barkston", which has been evolved by the mechanical engineer at a Yorkshire colliery. This apparatus is novel in design, as the filter appliance is arranged with two separate containers, one in the form of a cyclone dust collector for dealing with the coarse dust and the second a fabric filter which retains the fine air-borne dust carried over from the cyclone separator. The suction hood resembles others described above, but in this instance it is locked into position on the rock face by the expansion of five serrated steel fingers, similar to a boiler-tube expander.

"Collier" dust trap.- The most recent dust trap submitted for test and officially approved by the Chief Inspector of Mines is called the "Collier." This is the invention of a mechanic at a colliery in South Wales. It is somewhat similar in design to the "N.A." trap, but has one important improvement, namely that the coned member, which is hammered into the collar of the borehole for the purpose of securing the dust trap in position, forms a separate entity. This coned member is constructed of mild steel and can be made in a number of different sizes. The body of the dust trap proper, which is constructed of aluminum, is secured to the coned member by a simple bayonet joint.

Kadco dust-control system.- The results of tests made by a lead-mining company (278) of 3 Kadco dust-removal units--2 suitable for raise work and 1 for drift operations--may be of interest to those who think that even if an apparatus is satisfactory for removing the dust in underground work it may not be desirable as regards efficiency and cost of operation. The hoods of the Kadco system, through which the drill steel is drawn, control the dust at the drillhole; the dust is conveyed through rubber hose or pipe to a collar, where it is removed from the air stream, and the air is then available for recirculation in the working place. The dust is removed effectively as shown by dust counts made by the Metropolitan Life Insurance Co. A report of some of the results of the mining company's tests of this sytem of dust control follows:

The results of the drilling tests, which covered a period of about 4 months, from an efficiency or cost angle, indicate that:

1. When using Kadco, the number of minutes consumed per foot of raise was 3.899 in comparison with 5.570 when drilling dry. In other words, the drilling time, and therefore the cost, was approximately 30 percent less when the dust was removed. It is probable that the comparison would have been even more favorable if the start of the test had been postponed until the miners had become thoroughly familiar with operations of the dust-control units.

The average number of feet drilled per piece of drill steel dulled, when using Kadco, was 12.16 in comparison with 7.08 with the dry method. It is believed that the large saving in drill steel is probably due to better alinement of the drill steel and machine. There is not the same tendency when drilling with Kadco equipment for an angle to be formed at the chuck between the drill steel and the machine as when drilling wet or dry. Again, when using the Kadco equipment the location of the point of the bottom of the leg of the stoper drill is not changed while the hole is being drilled, as is often the case when drilling by the usual methods. Both of these factors cut down the amount of binding of the drill bit in the hole which prolongs the life of the gage of the bit.

2. The number of minutes per foot of drift was approximately the same on both the Kadco and wet methods, being 3.226 in comparison with 3.106. If, however, the figures for 2 of the 24 days were omitted from the Kadco average, for the reason that an extraordinary amount of time was necessitated on these 2 days due to extensive slabbing, which time was not consumed during the wet dust period, the comparison would show slightly in favor of Kadco. But for all practical purposes, the time consumed was the same for both methods. There was, however, an appreciable saving in drill steel when using Kadco, being 15.2 feet per piece of steel dulled, in comparison with 7.13 with the wet method. The 100 percent greater life of steel is undoubtedly due to the fact that the cuttings are quickly removed from the hole and are not ground up to very fine sizes, causing excessive wear of the gage of the bit as is the case in the wet method of drilling. This is clearly shown in the material taken from the dust collector, the coarser sizes being surprisingly large and forming a large percentage of the total material removed.

The advantages of using Kadco equipment in raising are:

1. The hood extension column used on the stoper type of pneumatic drill keeps the machine in correct position at all times. This enables a machineman to change steel very quickly and easily, as the machine merely slides down the column, the steel is taken out, and new steel put in, and drilling is resumed.

2. The extension column serves as a very important safety device in the event that a piece of steel breaks, as the machine only rises to a certain point, where there is an automatic cut-off of the air in the leg used to raise the machine. Also, the hood acts as a support in starting the hole and therefore greatly lessens any chance of an eye or other personal injury.

3. Another advantage is that the gases which are usually present in the face of a raise after blasting are not merely stirred up or diluted by the exhaust from the drill, but are sucked out of the raise by the suction blower on the collector.

4. If water is used for drilling in a raise, it constitutes a constant source of annoyance to the drill operator, who is more or less thoroughly soaked at the end of his shift. In addition, the water running down the raise makes the ladders and footwall slippery and results in a definite safety hazard. It was because of this risk, coupled with the chance of men contracting pneumonia or colds in the severe winter weather that is experienced at Balmat, that dry raising was used by the St. Joseph Lead Co.

5. The increased greater drilling speed using Kadco equipment indicates a considerable saving in compressed air consumed per foot drilled, up to approximately 34 percent in the case of raises.

The disadvantages are:

1. The extra weight of the equipment, being some 11 pounds for the hood and extension column, also the effort required to pull up the extra hose in the raise. If the wet drilling method was used in the raise, there would be little or no difference in time and labor required to handle the water hose, as compared to the Kadco hose.

2. The time required to empty the dust collector. In the small unit this must be done twice a shift. The fine dust is dumped under water in one of the pump sumps or water ditch, and the coarse dust is placed in an ore car and available for milling operations.

We feel, however, that from purely a standpoint of efficiency, the time lost in these two disadvantages is more than made up by the fact that the machinemen are able to stay up in a raise as long as desired, whereas when drilling dry the average drill operator did not stay for more than 2 hours before coming down to the level to get out of the dust. It has also been our practice not to keep a man constantly on raisework, even though the dust is mainly dolomite and contains a negligible amount of silica. The resultant constant changing of men does not tend to increase efficiency or output.

In drifting operations there also seems to be some advantage in using Kadco instead of the wet method, although the results are not as outstanding as when a stoper type of drill is used:

1. There is a definite saving in drill-steel consumption.

2. There are no water lines to put in nor water hose to burst. No water needles in the drills to cut off, if a shank on the drill steel is slightly defective.

3. The lubrication of the machine is much better when drilling dry than when drilling wet, and this condition should result in lower repair cost. No comparative repair-cost figures, however, have been obtained.

4. The laying of track is done much quicker, as the bottom of the drift is not wet.

5. The wet health hazard is eliminated, and the eye and other personal risk is lessened.

6. The general mine ventilation is improved, as instead of dust-laden air moving away from the working place, the air circulation is reversed and toward the drill, by reason of the suction.

The disadvantage is the extra equipment of hoods, hoses, collectors, and the cost of same. The power consumed in running the 4½-hp. suction-fan motor on the large collector and the 1½-hp. motor on the small unit is a small additional operating cost.

Pyrene Foam.- The Mines Department of Great Britain has recently approved a new apparatus called the "Pyrene Foam" (279) for trapping dust. This apparatus consists of a 5-gallon foam-generating container, weighing about 40 pounds and housed in a substantial casing with 2 apertures at the top for convenience of transport and for hose connection to and from the apparatus. All fittings are protected against damage from the inevitable rough usage inseparable from mining. The foam-forming liquid, a noncorrosive vegetable product, is supplied in sealed tins in a concentrated form for diluting with water near the site of the drilling; a gallon of the diluted solution produces about 15 gallons of foam. The container is connected to the compressed-air supply through a reducing valve of the diaphragm type, which reduces the normal mine-air pressure to about 30 pounds per square inch and which forces the foam liquid through tubes inside the container especially constructed to split the liquid stream into drops; a supply of air aerates the drops into a foam with a volume 15 times that of the original liquid. It is this expansion which so materially reduces the quantity of liquid required for dust-trapping. The generator usually contains two foaming tubes, but more can be fitted to work a greater number of drills from each container. The tubes are provided with valves to regulate the flow of foam; the valves are closed when

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the tubes are not in use. The important problem in the research which preceded the design of the apparatus was to produce a foam which would not break down when passed through a long length of small-diameter hose and the restricted passages through wet drills. This has been done so successfully that lengths of 120 feet of $\frac{1}{2}$-inch or $\frac{3}{8}$-inch hose may be used safely to connect the drill to the foam generator, thus reducing the time spent in moving the container and allowing it to serve more than one drill. The quantity of compressed air used is negligible; the drill usually requires only 1 gallon of foam liquid per hour as compared with about 1 gallon of water per minute for the jet of a water-fed drill. The foam is noninflammable, noncorrosive, does not impede in any way the working of the drill or cause any tendency to stick, and exerts a cooling effect on the drill. The 5-gallon container will supply enough foam to last a shift, or the foam can be delivered into a central header from which connections can be made to a number of drills. A spray nozzle can be used to apply the foam to the floor, roof, and sides of working places; to material before being broken for loading; and to material being loaded to prevent dust during working operations.

Dust respirators.- Although some form of respirator has been in use for generations to protect against dust (280) it has not proved satisfactory because it is uncomfortable to wear, and the filtering medium clogs rapidly with dust and exhaled moisture, which greatly increase resistance to air flow and impose extra and often excessive effort in breathing. Some of the discomforts may become pronounced, such as the pressure at the edges in contact with the face; the heat caused by the face cover; the warm, humid, exhaled air in contact with the face; rebreathing the trapped exhaled air; and prevention of cooling by evaporation and radiation. In cold weather the heat effects are not uncomfortable. Some respirators fit the face so poorly that much of the air is inhaled through openings between the face and respirator without removing the dust. One reason that respirators have not proved successful is that workmen will not wear them (280) for any length of time, probably because of the discomforts described above.

In 1926 the United States Bureau of Mines summarized the results of an investigation of the construction and filtering efficiency of dust respirators as follows (280):

1. The efficiencies of the industrial dust respirators in restraining tobacco smoke range from 5 to 33 percent when the air is passed at a rate of 32 liters per minute; a gas-mask canister with 2 filters of absorbent cotton showed 63 percent efficiency. The Fogler flat felt filter was most efficient, showing 97 percent.

2. The efficiencies against silica dust floated in air range from about 9 to 70 percent for the dust respirators, or about twice the efficiency against the tobacco smoke; most of the silica particles were 1 micron in diameter or 4 times the diameter of the tobacco-smoke particles.

3. As the dust most injurious to miners, stoneworkers, and many others engaged in dusty trades is about 1 micron in diameter the respirators, if work can prevent a considerable amount of dust, but not all of it, from being inhaled.

4. Although the laboratory study has shown that most dust respirators are not highly efficient in removing tobacco smoke (very difficult to arrest) from air, a filter that removes 50 percent of the tobacco smoke from air flowing at the rate of 85 liters per minute is very efficient in restraining the ordinary dusts encountered in industry and also the smokes, such as those from burning wood or other carbonaceous material, that city firemen encounter. Hence, the Bureau of Mines adopted a 50 percent efficiency against tobacco smoke by the laboratory tests as a standard requirement, besides other requirements, for the approval of respirators or gas masks to afford protection from smoke or dust.

5. As the laboratory tests of the dust respirators were severe, the low efficiencies given do not indicate the general efficiencies of these respirators under all industrial conditions. Much of the dust encountered in industry is less difficult to arrest, and the over-all efficiency of the respirators in actual service is correspondingly higher. The tests thus show that, as a rule, these respirators are of much value in removing injurious dust from inspired air.

6. The discomfort caused by respirators covering the face--the heat engendered thereby, the irritation of the skin at contact with the respirators, and the resistance to the flow of the air breathed--are the most serious disadvantages of respirators. The resistances of industrial dust respirators to air flowing at 85 liters per minute were 0.25 to 1.5 inches of water. The Fogler flat felt filter had a resistance of 2.25 inches and the gas-mask canister 3.6 inches.

7. A man wearing a gas mask can work hard only about half an hour; then the extra effort caused by the resistance to breathing compels him to stop to rest or greatly reduce his exertion. The resistance of the dust respirators, although it causes some discomfort, does not seriously interfere with a man's exertions until the filter becomes clogged with deposited dust and the resistance correspondingly increased. The filter must then be cleaned or freed of dust, or it must be replaced by a fresh one.

8. Filters of various fabrics, including cheesecloth, canton flannel, unbleached muslin, closely woven bleached muslin, filter paper, and absorbent cotton, all made for test purposes so as to expose exactly 100 square centimeters of filter area, were tested against tobacco smoke and against silica dust in air flowing at a rate of 10 liters per minute. Each material was tested in a single layer and in multiple layers. Results showed that each layer of fabric (in effect) removes about the same proportion of smoke or dust that penetrates to it before the filters become clogged or altered by deposits of an arrested material, such as silica dust. Consequently, then the efficiency of a single ply of a filter is known, the efficiency of any multiple-ply filter of that material may be calculated.

9. Silica dust clogged filters rapidly and increased the resistance to air flow, but some materials were more resistant to clogging than others. The dense filters of paper or closely woven muslin clogged most rapidly; filters of loose texture like cheesecloth or absorbent cotton clogged the least.

10. The efficiencies of the filters were increased by clogging with dust until eventually many filters gave an efficiency of 100 percent.

11. Tobacco smoke did not clog filters, and there was no increase in efficiency as the smoke was deposited.

12. A few tests were made with woolen fabrics, but they proved to be no better as filters than cotton fabrics of similar texture.

13. The efficiency of the filters decreased somewhat with an increase in the rate of air flow. Sometimes a cotton fabric with a nap showed a decrease after humid smoke had wet it and the moisture had caused the fibers of the nap to adhere together.

14. The resistance of the filters to air flow increases in proportion to the number of plies of fabrics after the first ply. The first filter layer shows a somewhat higher resistance than the additional ones.

15. The resistance of fabric filters to air flow is very nearly proportional to the rate of air flow.

16. Air filters of high efficiency can be made with a sufficient number of plies of material that has a low efficiency per single ply--cheesecloth, for example. Such filters have less resistance to air flow than equally efficient filters made of fewer plies of the higher-efficiency materials, such as closely woven muslin.

17. The thicker filters of loose-textured material clog less rapidly than equally efficient filters composed of fewer plies of tightly woven material.

18. A new type of dust respirator was designed and constructed according to the principles brought out in the tests. This respirator consists of a large filter of Canton flannel made into a cap or turban for the head. Air filters through the Canton flannel to the interior, passes through a check valve, and then is conducted through a rubber tube running over the forehead and between the eyes to the nose, which is covered with a small rubber nose cap. At an air flow of 85 liters per minute the efficiency of this respirator is 58 percent against tobacco smoke and 93 percent against silica dust.

19. The data presented and the principles outlined may aid manufacturers in improving dust respirators.

20. Although the use of respirators should be encouraged among workers in dusty industries, a respirator cannot be considered a final safeguard. In mining and in other industries effort to prevent the formation of dust and its distribution by the air, by the use of hollow drill steel and water, and by sprays on the undercutting machines should be continued.

After studying the development of a satisfactory respirator for several years the Department of Scientific and Industrial Research in collaboration with the Home Office, War Office, and Mines Department of Great Britain (255) perfected a respirator which they consider ideal from all standpoints. According to Hay (255):

> A number of these respirators have been manufactured for exhaustive trials to be carried out under actual working conditions in mines and quarries, and it is hoped that a problem of great importance is now on the point of being solved.

On August 20, 1934, the United States Bureau of Mines issued Approval Schedule 21, Procedure for Testing Filter-Type Dust, Fume, and Mist Respirators for Permissibility (281). Respirator filters are subdivided into classes according to the type of atmospheric particulate matter against which they are designed to protect. Type A is designed for protection against mechanically generated dusts resulting principally from the disintegration of a solid, such as the clouds produced in the various processes of mining, quarrying, and tunneling and the various industrial operations of grinding, crushing, and general processing of minerals. A "man-test" is required to determine whether the respirator will give adequate protection to men performing light work in an atmosphere containing an irrespirable suspension of definite concentration. Six respirators have been approved by the Bureau under this schedule.

The Colliery Guardian (282) summarizes the precautions recommended by one of the British divisional mine inspectors to prevent dust production in coal mines as follows:

> Mr. Thomas Ashley showed that the problem facing everyone connected with coal mining was to keep under control the dust made in the processes of driving in hard ground and in rippings. It was, of course, impossible to prevent the formation of dust in this kind of work. The amount of dust, however, could be reduced when drilling by not allowing the drills to be used when blunt. In hard headings in the highly inclined measures found in nearly all coal mines of the Swansea division the beds passed through were constantly changing. These varied from soft clifts to sandstones of all degrees of hardness, the latter giving rise to dusts, the breathing of which should be avoided as much as possible. During recent years a number of cases of silicosis had been certified by the Medical Board, of colliers and other classes of workmen in which there had been apparently no history of drilling or working in hard headings or in hard rocks. Preventive measures had not yet been fully worked out for these except possibly the use of respirators, but many cases of silicosis were certified by the Medical Board amongst workers in hard headings and sandstone rippings, and in these preventive measures had been developed to enable the dust to be kept under

control during drilling by means of dust-trapping devices, the use of water-fed drills and by foam injected into the shot hole. Very many of these devices were now provided for use in the mines of the division where mechanical drills were used both in hard headings and in rippings, and their advantages were, without doubt, now fully realized by both managers and workmen. However, the management's duty did not end with providing the dust traps or other means, but it was up to them, as well as the men engaged on the work, to see that proper use was made of the traps. Care needed to be taken that the position of the shot holes was so arranged that the hood of the trap could be used effectively and that the apparatus itself functioned properly. Dust traps were easily liable to become damaged. The best way to guard against this was for frequent inspections to be made of the traps by a skilled mechanic and spare traps and spare parts should be provided, so that the apparatus could be kept in proper working order. These were matters to which the inspectors of mines paid constant attention during their daily inspections underground, and by the use of the konimeter the efficiency of the preventive measures in use was determined. On an average there were no less than 30 hard headings being driven at any one time in that division. It was hardly necessary to add that the dust collected by a trap should be so treated that, when being emptied, it was not dispersed into the air, and that where the rubbish had to be conveyed away to be emptied the trams should be dusttight.

Dust also arose from the shattering effect of the explosive upon the rock following the firing of shots. This, of course, could not be trapped or its formation entirely prevented. Proportioning the charge to the work to be done, as well as care in placing shot holes, would result in less breakage of the rock and in a reduction of the dust. In this connection, however, the adoption for stemming the holes of a mixture of clay and sand would, owing to the greater efficiency of the work done by the explosive--thus allowing less explosive to be used--tend to reduce its shattering effect and so minimize the formation of fine dust. And when speaking about shot firing, there was just one other point he might mention. A shot not only produced fine dust by shattering the rock but it also raised into suspension all dust lying in the immediate vicinity. If, therefore, the area contiguous to the shot was kept as clear of dust as was practicable, less dust would be raised into suspension when the shot was fired. Since the dust formed and raised by the concussion of the shot when firing explosives could not be prevented it was necessary that means should be adopted to avoid as far as possible the exposure of the workmen to it. Shots should be fired, as far as practicable, before mealtimes and at the end of the shift, so that as long an interval of time as possible elapses before any workmen needed to return to work at the face. Under any circumstances as long a time as possible should be allowed to elapse before entering the place where the shot or shots have been fired. The better the ventilation--and it should be remembered that velocity was equally as important as quantity--the quicker would any concentration of dust be rendered harmless or removed.***

To sum up, the problem of keeping the dust under control amounts to this:

First, take all practicable steps to limit the amount of dust produced by--

1. Reducing the amount of shot-firing to a minimum and consequently the number of shot holes to be drilled;

2. Seeing that the drills are kept sharp;

3. Maintaining the area in the neighborhood of shot-firing as clear of dust as practicable;

4. Proportioning the explosive charge to the work to be done;

5. Seeing that the shot holes are properly placed with respect to the work to be done;

6. Using slightly moist sand and clay stemming mixture for tamping.

Secondly, take all practicable steps to control the dust that is produced and so prevent it from being breathed by workmen by--

1. Shot firing, only when the minimum number of persons are in the mine, preferably between shifts. This precaution would also apply when gobbing is being done in dry and dusty places;

2. Maintaining an efficient ventilation during drilling and also while filling the rubbish into trams;

3. If necessary, fixing a definite interval between the firing of a shot and the return of the workmen;

4. Collecting the dust made when drilling, by dust traps, water-fed drills, or by using foam.

Dust filters.- In a paper on Mine-Air Filtration Cowles and Flugge-de Smidt (283) describe methods tried in South African mines for removing dust produced in ore bins and at tippler stations. Dust so produced is added to the air currents if the bins or ore passes tend to upcast, as they usually do. Although sprays and doors are of some assistance the only effective means of preventing this dust from rising is to induce constant downcast currents of air through the tipping points. In one instance the dust-laden air, drawn from below the tippler level, was led direct to the upcast shaft; in another a similar installation discharged into a large worked-out area, where much of the dust settled; and at East Geduld, where neither of these systems was possible, flannel-bag filtration was successful. The paper by Cowles and Flugge-de Smidt deals mainly with air-filtration experiments and filter plants at ore passes but also includes descriptions of a filter-bag installation used in a development section to permit double-shift blasting and of the filter plant attached to the surface crusher station.

Flannel was found to be the best filtering medium for the bags. Konimeter counts after filtration range from 60 to 100 particles per cubic centimeter, and the weight of dust caught per day is approximately 18 pounds. The authors (283) describe the filter plant as follows:

> The main tippler station at East Geduld is on the 5th level. Some 1,500 tons are tipped into both the north and south ore passes daily, and in addition about 1,000 tons, tipped on the 4th level, enters the south ore pass just below the 5th level. 400 tons are tipped in the waste pass. The two main ore passes join above the underground sorting station. All the tipplers had a tendency to upcast, causing dusty air to pollute the main fresh-air intakes. The dilution beyond the tipplers was such that counts of from 100 to 150 particles per cubic centimeter were seldom exceeded. Bad conditions prevailed when rock was tipped into empty bins or when the 4th level box was run into the south ore pass. At such times surges of upcast air gave pyramids of dust on konimeter spots sampled at the tipplers.
>
> It was decided to cause all the tipplers to downcast by exhausting sufficient air from each of them and to filter this air. A vertical winze, 9 feet diameter was sunk in a central position to a depth of 24 feet and crosscuts were driven from the bottom of the winze to each of the three passes. A filter chamber was cut from the winze, below the station level, and lined with concrete in order to retain the strength of the station pillar. Filtered air divided equally into the intakes to the north and south sections of the mine. The completed size of the chamber is 30 feet by 11 feet by 8 feet high. The fan selected was a 30-inch Aerex capable of circulating 18,000 c.f.m. against 2½-inch W.G. It has four slender propeller blades and no guidevanes, so practically no dust collects in the fan. The motor is enclosed within the fairing in the fan, which itself is made to draw fresh air from outside through the motor, in order to prevent clogging by dust. The fan exhausts air from the vertical winze through 36-inch piping and from the bottom of the 4th level box through a 16-inch pipe. It delivers into a large header with nine 16-inch-diameter outlets to each of which a flannel bag, 18-inch diameter by 20 feet long, is attached. The bags are supported by means of felt-lined metal rings which are suspended from the roof. The filter fabric area is approximately 1,000 square feet, giving a linear speed through the cloth of about 20 f.p.
>
> All three tiplers became strongly downcast when the plant was started up, and it could run for a week before the resistance of the bags rose to 3-inch W.G. The bags are now changed twice weekly, and the resistance does not rise above 2 inches.
>
> The efficiency of the dust chamber has far exceeded the writers' expectations. Except during the first day's run with new bags it has been practically impossible to obtain a konimeter spot and even a Zeiss konimeter, taking 25-cc samples, has shown no spot on an untreated slide. The Greenburg-Smith impinger apparatus was used to obtain comparative results. The air to be sampled by this instrument is made to impinge through a nozzle onto a flat plate under water. 200 cc of distilled water in a glass bottle are used for an ordinary sample.

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We believe that the filtering accomplished in this plant is of a high order, firstly, because of the inability to obtain konimeter spots and, secondly, because of the optical properties shown by the Greenburg-Smith impinger samples of filtered air, and we claim that the filtration of over 99 percent, obtained in the last 2 tests shown in the table, represents the normal efficiency of the plant. These results are due largely, in our opinion, to the dilution that lessens the concentration of dust passing into the bags. ***. We were also concerned with the discrepancy between the size frequency of the particles in a Greenburg-Smith impinger sample of unfiltered air and that of the dust caught in the bags. The former revealed nothing over 6 microns while particles up to 50 microns were found in the latter. Our feeling that something was wrong with the sampling of unfiltered air was supported by a comparison of the actual dust caught with the theoretical amount called for as revealed by the average of five 24-hour Greenburg-Smith tests. Only 14 pounds of dust per week was called for, whereas 80 pounds of dust was caught. It appeared possible that the unfiltered air was not representative, either as regards dust contents or size of particles, due to sampling through a nozzle facing downstream. This was tested out by turning the nozzle toward the fan with the results shown in the last 2 tests which, incidentally after averaging, called for a dust catch of 77 pounds per week and showed particles up to 30 microns in size.

During a discussion of the paper by Cowles and Flugge-de Smidt (283) the president of the association called attention to electrical precipitation, which is beyond the experimental stage, many plants now very successfully removing dust, gases, and noxious fumes in various industrial processes. Jeppe (283) stated that--

> The tenacity with which the grim battle against silicosis has been fought and is being fought is one of the epics of Rand mining. It may be that victory will never be complete: at least, however, success has been gained on many fronts and the struggle never ceases.

He also made the following comment on the investigations reported by Cowles and Flugge-de Smidt:

> The success with which these investigations have met is very clearly shown in this paper now before us: Dustcatching efficiencies of 98 percent and 99 percent have been obtained on the plants installed at the East Geduld mine, and it has been found possible even to eliminate to a negligible point the dust produced by blasting, so that double-shift blasting has now been made practicable. This must be recognized, I think, as a wonderful achievement, far in advance of what could have been anticipated a few years ago.
>
> This paper also, I think, has to a considerable extent crystallized our knowledge of the main essentials for efficient dust-trapping:
>
> 1. The downcasting of the tippler or bin by the installation of a fan.

2. The collection of this dust by passing the air through appropriate filtering material of such an area that the linear velocity is about 20 f. p. m., and

3. The exhausting of this treated air into adequate currents of air for dilution.

All these factors are essentials.***.

There is one point in connection with these dustcatching plants with which the authors have not dealt in detail, and which merits, I think, our close attention; and that is, Do these filters catch the finest dust?***.

Professor Kettle is of the opinion that it is the finest dust which causes silicosis--dust so small that it can be absorbed and at least partially dissolved by the lung tissues and which then acts, in some unknown way, but probably chemically, as an irritant, causing silicosis. He states that his best results--best, that is, from the scientific point of view of causing silicosis--are obtained with flint dust which is 70 percent less than 0.8 micron in size--that is, of a size smaller than can be seen with an ordinary microscope.

With this viewpoint Mr. Adler has suggested that filter plants should be designed for two stages--the first to catch the coarse dust and the second to catch the fine dust. His theory that the flagellae or cilia of flannel catch the fine dust, when the velocity of the impinging particles and the velocity of the waving cilium are equal, is of more than academic interest; if it be accepted then the best materials to use as filters, ceteris paribus, are obviously those with the most efficient supply of such flagellae; and this indeed is, I think, borne out in practice.

It may be mentioned, however, that the possible nonelimination of this finest dust has been allowed for, to some extent at least, in these filter plants at the East Geduld, by the subsequent dilution of the treated air: for it is known fairly definitely that efficient dilution nullifies the harmful effects of dust of any size.

Dust Control in Industries Other Than Mining

Ballantyne (108) directs attention to the fact that the ameliorative measures adopted almost universally in dealing with silicosis have not called for the complete suppression of dust--the unattainable ideal--but have followed the lines of preventing the inhalation of dust as far as practicable, keeping the worker under medical observation and control and paying compensation if the worker is attacked by the disease. He states that the processes carried on in the industries vary so widely and call for such different treatment that each must be studied alone. Quarrying rock, grinding cutlery, and making pottery have little in common, except that they give rise to siliceous dust; therefore, the means adopted for allaying, trapping, or withdrawing the dust obviously cannot be the same in all instances. There is a broad scope for ingenuity in the design of plant suited to the needs of each.

Many of the methods of value in control of dust in mines--as the use of water, ventilation, and dust collection--are largely applicable to other industries.

Smith (284) states that the prevention of silicosis may be aided by such combinations of the following measures as are feasible: Substitution of non-silicosis-producing material, such as a metal abrasive for sand, nonsiliceous parting compounds for molds in foundries, and clay instead of flint in bedding potteryware for baking; enclosure and segregation of dusty processes, as the use of sand-blasting cabinets; local exhaust ventilation for the removal of dust at point of origin; suppression of dust by water--sprays and steam help in conjunction with other methods but should not be overestimated; general artificial ventilation; plant cleanliness, which is as important as upkeep of protective equipment; direct protection of the worker, although masks and helmets have serious operating limitations; alternation of work, which should be more frequently applied; medical supervision; education--workers need to be impressed with the risks, instructed in the use of equipment, and encouraged to submit to physical examination; and dust-counting to check the efficiency of the measures should be a part of preventive programs.

Dust Control in Abrasives and Grinding Industries

An investigation made in 1919 by Winslow and Greenburg (285) revealed that establishments devoted to the manufacture of abrasive materials may present conditions as regards aerial dust content scarcely equaled in any other industry. In the carborundum-grinding department of the factory it was found that virtually no precautions had been taken; in the aloxite department the grinding room was provided with enclosed machinery, and the lathes were equipped with an exhaust system which the management believed was adequate. However, a careful examination of the system showed that it was gravely defective in several respects. Its principal shortcomings were cited by the authors as typical of conditions frequently noted in the inspection of exhaust systems designed or operated by those unfamiliar with the principles of efficient dust removal.

> The exhaust ducts were so small that their high frictional resistance greatly increased the cost of operation and made it very difficult to maintain an adequate suction pressure. Furthermore, such small pipes tend to clog with lint and dust, and dealing with the latter tendency was made doubly difficult because an insufficient number of clean-out handholes was provided.
>
> The system as installed had been allowed to deteriorate seriously for lack of careful maintenance. Many ducts were noted with broken joints. The dust separators in some cases were in very bad condition, large holes being plugged only with rags and waste.
>
> Partly as a result of conditions noted above or, to look at it in another way, due to the lack of sufficient fan capacity to overcome these limitations, the suction pressure in the exhaust system was far too low to be effective. With the exception of the ducts serving certain shaving hoods, this pressure never exceeded that of a 1-inch water gage.

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Finally, the hoods for removing the dust from the immediate vicinity of the machines were defective in design. Such hoods should be so arranged as to apply as large a fraction as possible of the suction velocity in the exhaust pipes to the dust at its point of formation, and the suction should preferably be applied from such a direction as to take advantage of the tangential momentum imparted to the dust as it leaves the wheel. Instead we found most of the machines entirely lacking hoods, the exhaust duct merely terminating in a funnel-shaped opening below the center of the machine spindle so far away that the velocity of the exhaust was scarcely perceptible at the face of the wheel.

The disease-prevention value of substituting a less dangerous for a more dangerous material in certain dusty industries is indicated by the experience in an ax-grinding plant in Germany. The director of the research department (286) was asked to determine the reason for the sudden increase during the preceding 6 years in the number of deaths due to silicosis and silicotuberculosis among the workmen in the plant. The most striking changes of operation during this period were the elimination of the midday dinner hour and the substitution of Pfalz for Eifel grindstones. Investigation revealed that the amount of dust resulting from grinding with Pfalz stone was considerably greater than with the Eifel stone. The latter did not produce weighable dust during the same period that the Pfalz stone produced 13.3 to 37.7 mg in 1 m^3 of air. The dust count for the Pfalz stone was correspondingly higher than that for the Eifel. Analysis showed that the Pfalz stone was 33 percent higher in silica but lower in aluminum oxide than the Eifel stone. Pfalz dust showed 0.9151 gram of crystalline silica per gram of dust, while the Eifel dust showed 0.623 gram of the same substance. The Eifel is considered by far the less dangerous stone especially since it contains a larger amount of bond in the form of aluminum oxide, which tends to make the dangerous silica particles far less dangerous in the dust. According to Clark (286), this paper is of interest because it supports the belief that the higher the silica content the more dangerous the dust, and the higher the dust count the greater the health hazard (provided the dust is dangerous). Aluminum oxide is not a factor in the production of silicosis; this fact is of special interest because most artificial grinding wheels are made of aluminum oxide crystals held by a vitrified bond. The results of the investigation confirm the value of industrial-hygiene plant control and continuous successive examinations of employees to determine whether a health hazard is developing.

In 1933 Bloomfield and Greenburg (287) reported the results of a study of air-pressure abrasive-blasting operations in the United States made by the United States Public Health Service during 1929-31 in cooperation with the National Safety Council. Preliminary surveys were made of 355 pieces of abrasive-blasting equipment operated by 536 workers in 44 plants in 8 States. In 64 percent of the instances the abrasive used was sand; in 34 percent, metal (steel grit and shot); and in 2 percent, a mixture of sand and metal. The surveys included inspection and classification of equipment as to kind, quality, maintenance, general housekeeping, age of installation, and type and maintenance of respiratory protective devices. As a result of these preliminary surveys, detailed studies were undertaken in 28 shops in Connecticut, Michigan, Wisconsin, and Illinois. The shops contained 194 pieces of abrasive-blasting equipment: 27 percent, rooms; 33 percent, barrels; 7 percent, tables; 10 percent, cabinets; and 23 percent, others. Virtually all the dust in the air of the workrooms was less than 3 microns in size, the model size was between 1 and 1.5 microns, and only 1 percent was less than 0.5 micron. When sand alone was used as the abrasive the quartz content of the dust in the air ranged from 42 to 98 percent, depending upon the cleanliness of the castings being blasted; when sand and metal mixtures were employed the quartz content of the atmospheric dust averaged 44 percent; and when metal abrasive was used it averaged 3 percent. With sand abrasive the average dust concentration to which the workers were exposed for the different types of blasting equipment, in million particles per cubic foot of air, was: Rooms (exposure under helmets with nonpositive pressure), 241; rooms (exposure under helmets with positive pressure), 4.7; barrels, 29; tables, 25, cabinets, 3; automatics, 24. When metal abrasive was used the concentrations, in million particles per cubic foot of air, were: Rooms (exposure under helmets with positive pressure), 1.9; barrels, 15; tables, 17. Even in a well-designed and properly ventilated room with metal abrasive on clean castings the average dust concentration in the workroom air was 49 million particles per cubic foot, indicating the necessity of special protection for the worker. As a rule, this protection consisted of helmets, masks, and hoods. With positive-pressure helmets the average dust concentration in the air to which the worker was exposed was 5.5 million particles per cubic foot (maximum, 25), whereas with nonpositive-pressure helmets the average was 581 (maximum, 1,912).

A study of the amount of dust in the air supplied to the positive-pressure devices (287) disclosed an average of 1.8 million particles per cubic foot and a maximum of 7.9 million. Tests on the amount of air supplied showed that most of the devices received 4 to 10 cubic feet of air per minute. Special experimental studies indicated that the provision of a positive supply of 6 cubic feet of dust-free air per minute will protect the worker under the operating conditions now in practice in abrasive-blasting rooms (no blasting-room dust filtered into the helmet when this amount of air was provided). When abrasive-blasting was in progress in rooms there was an average of 20 million particles per cubic foot of air and a maximum of 180 in the general workroom air, whereas when no blasting was in progress these values were 3.5 and 9.1, respectively. It was observed that poorly designed and maintained equipment was responsible for much of the pollution of the workroom atmosphere. For example, provision of exhaust housing about barrels reduced the average concentration of dust in the workroom from 38 to 2.2 million particles of sand and from 25 to 6.2 million particles of metal. Studies of equipment regarded by manufacturers as ideal and properly maintained showed an average dust concentration of 1.7 (barrels), 0.9 (tables), and 1.9 (cabinets) million particles per cubic foot of air. The maximum in no case exceeded 4.5 million particles per cubic foot. Bloomfield and Greenburg (287) concluded that dissemination of dangerous amounts of dust into the air could be prevented by equipment properly designed and maintained. However, this statement did not apply to rooms where respiratory protective devices would still be needed.

Assuming that employers in hazardous trades are not only willing but very anxious to protect their workmen, Willson (265) considers the steps by which they can approach this end:

These steps, undoubtedly, involve not only the expenditure of sufficient money to procure the best possible modern protective equipment (ventilators, exhaust systems, dust collectors, respirators, and the like), but also a readiness to face the expense of subjecting their workmen to thorough physical examination when employment starts and to reexamination at intervals not exceeding 6 months during the entire course of employment.

Employers should see that workmen are not exposed to the danger of tubercular infection from one another, that every facility in the way of dressing rooms, lunch rooms, and wash rooms is provided, and that every piece of protective equipment is kept in perfect working order.

Good housekeeping is, after all, one of the major considerations in the protection of workmen where there is dust of a hazardous nature. Dust-exhausting systems are of no use unless they are so applied to the work as to really carry off a large part of the dust and deposit it in receptacles where it cannot again work harm. Preferably the suction should draw the dust downward, away from the face of the operator. Many dust-collecting systems suffer from operation. In one plant visited last year the author noticed that the flue pipe between the inlet and the exhaust fan had opened at a joint so that air drawn in at the working entrance--if any was drawn in--tended to be thrown out again into the room at an elevated point, thus greatly augmenting the original hazard.

Then, too, sand-blast cabinets should be kept in perfect working order so that they do not send out into the atmosphere jets of dust from bad joints, leaky doors, or tattered curtains. Frequently the hoods over open sand-blasting cabinets are badly designed for protection against fine dust. Helmets used by sand-blast operators must be of modern design, supplying to the workman ample pure air; otherwise they are worse than useless.***.

Naturally, the first type of mechanical protection to come to our minds is that provided by systems of dust exhaustion. These are very effective when the inlets are applied close to the source of dust production, but their utility is less evident when they are considered in connection with suspended dust in large workrooms; in such open spaces ample ceiling ventilation and air cleaners are more helpful. There seems to be difficult in the way of the removal of fine-dust deposits in room spaces by any mechanical or electrical means other than the direct application of good vacuum-cleaning apparatus.

Protection of workmen by means of respirators is also indicated wherever the room air cannot be kept moderately free from dust, and, of course, doubly indicated in operations that are unusually dusty. In all kinds of sand-blasting, workmen should be individually protected, without fail. When possible, the form of respirator which provides for the workman an ample supply of pure, fresh air under direct pressure is certainly the best, provided every precaution is taken to see that the air is free from oily vapor and dust. There are, however, some occupations in and around plants where direct-pressure respirators cannot be employed without greatly impeding the necessary activity of workmen, and in such places much care should be taken in the selection of dry-filter respirators to see that these are not only efficient and easy to maintain in good working condition, but also are as comfortable as possible. The use of wet-sponge respirators is a doubtful practice, owing to possible variations in the quality and size of sponge, degree of wetness, cleanliness, and other factors.

More often than not employers urge that their workmen are not willing to wear respirators or that they wear them only occasionally. It must be evident to anyone that if this neglect of personal protection is actually practiced the situation from a protective standpoint could not possibly be much worse. Part-time protection can hardly be considered as protection at all--rather it is only a form of self-deception. If workmen will not wear respirators because of alleged discomfort, an effort must be made to provide them with devices that really can be worn during full-time employment; but full cooperation will probably not be attained without acquainting the worker with the danger to which he will be exposed if totally or partially unprotected.

Dust-Collecting Devices

Drinker (288) states that such devices as respirators and positive-pressure helmets should be considered only as emergency equipment if dustiness can be controlled by dust-collecting equipment and exhaust fans but that there are many processes in which respirators and other protective devices have an important place and probably will for many years to come.

The March 16, 1934, issue of Iron and Coal Trades Review (289) describes a dust collector for grinding machines:

> The suppression and removal of dust incidental to dry grinding operations is, of course, a legal obligation. Settling chambers, coke and water tanks are primitive forms of interception which are bulky, difficult to clean, and none too efficient when dealing with fine dust. Fabric dust collectors, though most efficient, can only be economically applied to large installations, where a number of grinders are working simultaneously.
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> The Visco dust collector has been specially designed for unit application. It is made in two types, that is, for light duties such as surface grinders, etc., and for heavy duties such as fettling, etc. Both consist essentially of a specially designed hood, an efficient exhauster, and the dust collector proper. The exhausters, which are designed for dealing with dust, may be either belt or direct motor-driven. In the standard designs they are mounted on the dust-collector casing, the suction inlet is connected to the grinder hood by galvanized ducting or flexible hose, the discharge being direct into the collector.
>
> The collector for light duties has a sheet-metal casing with baffle and deflecting plates acting as a settling chamber for the bulk of the heavy dust. The remaining light dust passes through a filter cell, operating on the well-known Visco principle of oilfilm-covered surfaces for the retention of the dust. The cleaned air is returned direct to the workshop.

For heavy duties, such as fettling, the cells would clog too quickly and a more efficient primary separator of the cyclonic type has been embodied, into which the dust-laden air is discharged at high velocity and is propelled by centrifugal force through the vanes into the collecting chamber forming the base. The efficiency of this primary separator is such that only a very small quantity of dust is carried by the air stream to be caught by the Visco cell.

From time to time the accumulated dust is removed from the collector casing, and the cell is cleaned by jarring it on the floor, which serves to remove the major portion of the accumulation of dust. The rest is washed out with hot soda solution; the cell is then dried and recoated. Whilst, as already stated, the collector was primary designed for unit application, there is, of course, no reason why two or more grinders should not be coupled to one suitable collector unit. Quite apart from a legal obligation, the beneficial effect of these dust collectors on factory conditions makes their installation well worth while.

According to Hatch (260), dust particles, generated by whatever means, require energy for their dispersion by means of air currents created by the operation of the dusty process. The counter-forces set up by the exhaust hood or other control device to prevent the dispersion of dust must be directed therefore (1) against the energy of the dust particles and (2) against that energy which produces air currents around the machine. Since these forces of dispersion are different in form proper design of equipment depends upon an understanding of their relative magnitude and the manner in which they act. The first lends itself to approximate mathematical analysis; the second depends upon the action of the dust-producing machine, and its evaluation requires careful analysis of the details of operation of the process. Hatch (260) states that, although his equations are not absolutely correct and do not hold over the entire range indicated, nevertheless they are correct in their relative orders of magnitude and demonstrate the important principle that whereas large particles may be dispersed by dynamic projection through still air microscopic particles, because of their relatively enormous surface area per unit volume, do not travel any appreciable distance by virtue of their own kinetic energy. He illustrates this principle by the action of a grinding wheel. Large particles are thrown off by centrifugal force and may be projected a considerable distance through still air, as the path of incandescent particles indicates. This force, however, is not great enough to disperse the fine particles, some of which may be carried in the air stream created by the "drag" of the large particles and thus escape with them; but most of them are dispersed by air currents induced by the fan action of the rotating wheel. Therefore an exhaust hood placed in the path of the incandescent large particles may not be adequate, as this neglects the fine (and nonluminous) dust that is dispersed with escaping air currents around the periphery of the wheel.

Exhaust hoods.- The concept of the dual function of an exhaust hood, arising out of Hatch's (260) analysis, suggests to him that for successful dust control three steps must be taken:

1. The kinetic energy of the large particles must be destroyed. These particles are not important hygienically, but they must be captured in order to prevent the escape of fine particles in the air stream created by their "drag." Their energy can be destroyed by means of barriers against which the particles impinge and lose their velocity, and the air currents induced by their motion can be dissipated by setting up countercurrents in the zone of dust generation by means of airflow into the exhaust hood.

2. Air currents created by virtue of the operation of the dusty processes must be eliminated through changes in the machine or more generally by the application of suitable baffles and housing to prevent their formation.

3. Air currents around the machine that cannot be eliminated must be changed in direction and made to flow into the exhaust system. This is accomplished by means of the potential gradient established between the suction opening and the surrounding air. Through hood design, the gradient must be maintained at the proper slope from the area of dust production and at a minimum slope from the so-called ineffective areas in which no dust is produced. A knowledge of the aerodynamic characteristics of suction openings is therefore essential to proper design.

Fundamental specifications for exhaust hoods cannot be established simply from a consideration of these factors. Experimental investigation must remain the most valuable aid to design. Nevertheless, the creation of a real science of dust control, which has been made necessary by the widespread industrial dust hazard, must be based upon physical laws. Empirical methods cannot be depended upon to relieve the heavy financial load that the dust hazard has placed upon industry.

In 1932 Dallavalle and Hatch (290) stated that the fundamental purpose f an exhaust hood is to create air velocity at the point of dust generation, ot to develop "suction", which is a failure as a measure of hood efficiency.

Dust traps.- The fact that a dust-producing operation is conducted outdoors oes not indicate necessarily that the air in its immediate vicinity is free rom harmful contamination. Rock-drilling is not confined to underground work ut is employed extensively in open excavation for building foundations, ubway cuts, and trenchwork, in quarries, and in many other places where urface rock is removed. As these operations are carried on in the open here wind currents serve to disperse the dust a silicosis hazard generally as not been associated with them in the past. However, Smith (133) demontrated that a real hazard exists, and a silicosis committee, appointed to dvise the New York Department of Labor on the preparation of a code to over this hazard, recommended the following (291):

1. Rock drilling, blasting, and excavating in New York City constitute a serious hazard to the health of the workers, owing to the constant exposure to silica dust, resulting in silicosis and tuberculosis. Remedial measures are urgently needed.

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2. Efforts must be made immediately to improve markedly, by controlling the dust concentration, the conditions under which the men employed in these occupations are compelled to work.

3. Compensation should be granted by law for disability due to silicosis.

A second committee was appointed to investigate dust-control equipment for use with rock drills and to formulate engineering specifications for its design and operation. The attention of the committee was directed toward the Kelly dust trap, which had already been used in conjunction with an exhaust system. An investigation was made of the efficiency of this device for use with pneumatic rock drills of the jackhammer type. Dust concentrations at the breathing zone of the drill runner were correlated with the rate of air flow through the hood. The rate of flow necessary to reduce the dustiness below the standard of permissible dustiness--5 million particles per cubic foot of air--was found to be 60 c. f. m. A number of check tests with the trap operating at this rate showed that the rate was satisfactory and that it could be used as the basis for design of dust-control equipment for rock drills of the jackhammer type.

The Kelly trap is a metal chamber designed to enclose the drill steel at the rock surface (291). No attempt is made to effect a mechanical seal with the rock or between the trap and the drill steel. The dust is captured by an air stream as it wells out of the hole and is carried into an exhaust system to which the trap is connected. Escape of dust particles through the openings between the uneven rock surface and the trap or around the drill steel is prevented by the air seal produced by the inflowing air. Unlike many previous attempts to capture the dust generated by rock drills, this device is not actuated by an ejector operated by the exhaust air from the drill. It is connected to an independent central exhaust system which may be designed to accomodate any number of drills and which is provided with a highly efficient dust-collecting plant. The trap, shaped very much like an inverted tin dipper, is split to facilitate insertion and removal of the drill steel, and the two halves are connected by a spring hinge. A simple catch keeps the trap closed during operation. The hole through which the drill steel passes is 1-5/8 inches in diameter, and the diameter of the steel is 1-1/4 inches or less; free rotation is thus permitted. The trap is ruggedly constructed to withstand the rough usage to which it is subjected in the field. Air is drawn through the trap into the exhaust system by the side connection, which is 2 inches in diameter. To provide flexibility of operation the connection to the main suction system is made by flexible hose, which may be in various lengths to accomodate different types of work. Since the trap encloses completely the point of dust generation Hatch, Kelley, and Fehnel (291) state that efficient operation will be attained when the air velocity through the openings between the rock and the trap and around the drill steel is great enough to prevent the escape of dust particles and when enough air motion is set up within the trap to carry away the large amount of material as it emerges from the hole. Therefore, the total air flow through the trap required to produce this condition must be determined experimentally, the criterion being the dust concentration at the breathing zone of the drill runner.

In 1933 the investigation of the efficiency of the Kelley device was extended to include its application to underground conditions. The tests were conducted in an experimental mine. They indicate (292) that for horizontal and down drilling a rate of air flow of 200 c. f. m. through the hood is sufficient to reduce the dust concentration at the breathing zone to below 10 million particles per cubic foot of air. The average count obtained with the drifter in the stoping position was 11.6 million, but with certain modifications in the hood it has been applied to the stopehammer with satisfactory results. Dust counts obtained with wet drilling, using both the South African and the American type wet drills, were higher than those given by the blower-type drill. The need for efficient and compact dust-disposal plants for underground work is pointed out.

At the meeting of the American Institute of Mining and Metallurgical Engineers in February 1934 Brackett (293) described a recent special vacuum producer and separator equipment. The outfit consists of a metal cap placed against the face of the rock, through which the drill steel can be inserted easily, and a vacuum producer, to which it is connected through a primary and secondary separator by means of flexible hose. Hoods have been adapted for vertical, horizontal, and stope drilling and are so arranged and mounted as to become immediately effective when collaring the hole and remain in place continuously. The drill steel can thus be changed without inconvenience or delay to the drill operator. No attempt has been made to maintain a tight seal between the hood and the face of the rock, as a large enough volume of air is maintained through the hood to draw a steady stream of dust-laden air, wet or dry, from the drillhole. The hood is held in position for horizontal drilling by an adjustable arm extending from the drill column; provision is also made for holding the hood in stope drilling. For vertical drilling in quarry or surface work the weight of the hood and the fit around the drill steel is sufficient to keep it in place. The hood and the first or primary separator are connected by flexible rubber hose, usually about 25 feet long, small enough in diameter to be handled easily and large enough to keep and maintain a sufficient vacuum when passing the required volume of air. The primary separator can be arranged for either wet or dry drilling, and 95 to 98 percent of the dust or sludge is collected at this point. This container is large enough to hold approximately half a day's drilling of 1 operator, and 1 is supplied for each drill. Extra primary separators should be available to allow replacements and removal of the full units to the surface or other convenient point for emptying. This practice prevents the possibility of stirring up any dust in the confined area and also allows convenient deposition of the dust, which incidentally has a market value. The primary separator should be located as close to the drilling as possible, usually about 25 feet. From the primary separator a second length of hose connects the secondary separator and vacuum producers; this can be either a stationary or portable unit, depending upon local conditions. For stationary installation these connections would be made to inlet valves located at convenient intervals on a pipe line extending throughout the entire project as in a central vacuum-cleaning system used in hotels, office buildings, etc. The vacuum producer and secondary or bag-type separator are mounted in some convenient place and exhaust into the general air either underground or on the surface. This type of installation has the advantage that it is not limited as to weight and it

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would be practicable to take care of as many as 50 drillers operating at one time. On the other hand, a portable unit must be small and light enough to be handled easily yet the filters must have enough bag area to remove the very fine particles of dust--less than 10 microns in size. Brackett (293) describes a portable vacuum producer which incorporates all these desirable features, including lightness, convenient carrying handles, and with powerful enough suction to remove all dust particles and maintain low dust counts. It consists of the bag filter or secondary separator, where the fine particles are collected, and the centrifugal-type vacuum machine mounted as an integral unit. This entire machine weighs less than 200 pounds and can be furnished with an electric or air motor or can be driven by a gasoline engine. The filters or bags are arranged so the dust collected is deposited in an easily removable pan at the bottom of the separators.

Brackett (293) stated that a unit arranged for handling two drills was tried out in a mine with very satisfactory results. The entire equipment, consisting of hoods, hose, primary separators, and secondary machine, was of such sizethat it could be lowered at one time in the lift and moved to the working zone on a regular mine timber car. Power for the electric motor was supplied by the trolley circuit, although air from the drill air line could have been used if an air motor had been available. Dust counts were taken of the general mine air and also at the driller's breathing zone while drilling was in progress, with and without the dust collectors running and with and without auxiliary ventilation. Holes were drilled with standard stope drills, wet and dry, to determine what might be expected from this type of protective equipment. The dust counts varied considerably; 2 to 14 times the original dust content was added when drilling without the hood. With the hood from ½ to 2 times the original dust content was added, and in all cases the final result was well within the usual accepted safe limits.

From dust counts taken under a wide variety of conditions Brackett (293 concluded that for underground work where the required dust count is not particularly low some form of water-tube drills or dry drills could be used with the dust collector. Where a dust count of below 5 million is desired in underground or confined areas water-tube drills will be required with the dust collectors. For surface work in quarrying and excavating hollow piston or air-tube drills with the dust collectors will maintain satisfactory working conditions.

Dust filters.- According to Ollett (294), every machine or industrial process that produces dust is a potential source of danger to the health of the employees, whether the dust is of wood, metal, or of a siliceous nature. Virtually all such machines can be fitted with hoods or hoppers into which the dust is drawn by an exhaust fan so that the bulk of the dust is caught at its source. He states that the very finest dust particles, which are the most harmful in their effect on the lungs, are also the most difficult to collect both at the point of production and in the dust separator. Coarse dusts can be separated readily from the exhaust air in the usual forms of settling chambers or cyclones in which the dust is thrown out by gravity or centrifugal force. Such devices, however, are ineffective for the elimination of fine impalpable dust particles; for the latter the automatic bag filter gives highly satisfactory results. This filter, as described by Ollett (294), consists of separate compartments, each having a group of special cloth filter bags suspended from automatic shaking gear at the top and fitting over spigots connected to hoppers at the bottom. The dust-laden air is drawn by the main suction fan into the bottom of the hoppers, where the heavy dust is deposited; the air then passes into the inside of the filter tubes from below. The fine dust is deposited on the inner surfaces of the tubes, and the clean air passes through automatic dampers into a common header, which is connected to the suction main. At regular intervals each compartment is isolated in turn from the suction fan and receives a supply of scavenging air from a separate fan, the filter bags at the same time being shaken by the automatic gear. The scavenging air passes through the bags from the outside to the inside, and this reversed air current, assisted by the shaking of the bags, dislodges the accumulated dust and deposits it in the hopper below. The hopper is fitted with a spiral conveyor, which discharges the dust through a rotary star valve into suitable receptacles. Ollett (294) states that this type of plant is especially applicable for the recovery of fine dusts of a harmful or valuable nature, as zinc oxide, soap powder, chemicals, ores, milk powder, flour, cement, etc., too fine to be collected in gravity or cyclonic separators. With this type of separator the warm exhaust air can be returned to the building from which it has been extracted, if desired for reasons of economy in heating costs, as the filtered air is virtually free of even the finest dust. Boyer (295), however, states that it is a common and dangerous practice in many dust-removal systems to return the filtered air to the plant to conserve the heat that would be lost if it were discharged outside the building. He found in five such systems, where dust counts had been made, that the air unquestionably was not fit for return except in one case. In one instance over 47 million dust particles per cubic foot were found in the air being recirculated--many times that considered a safe limit.

Ollett (294) mentions that the problem of dust collection at the rock face in underground works is more difficult than at machines on the surface, and very little progress seems to have been made so far in this direction. Portable vacuum exhausters of the turbine type with self-contained dust-storage bins were tried some years ago in a phosphate mine in the North of England. Flexible suction hose pipes were run from the machine to the rock face; a special form of hood through which the drill was inserted made a loose fit on the rock face. The exhaust from the compressed-air drill steel forced the dust from the end of the hole back into the hood, whence it was carried by the suction into the dust separator. He believes that this type of portable exhauster offers great possibilities in dealing with the dust produced at the rock face. Another and possibly the principal source of trouble experienced in the confined spaces of underground workings is the fine impalpable dust which remains floating in the atmosphere for a considerable period after the shots are fired. Ollett (294) calls attention to the fact that experience in the United States has shown that general ventilation of the headings is the most satisfactory solution known. The dust-laden air is exhausted and passed through large stationary filters, which must be of the automatic self-cleaning bag type already described; the clean air is returned to the headings. Ollett's statement would indicate that this method is used generally in the mines of the United States, but it is used in only one or two mines experimentally.

Brackett (293) has summarized the various methods employed in the attempt to maintain safe dust concentration in the air as follows:

1. Prevent the formation of dust. This would probably be the ideal solution if other means than drilling, shooting, or wedging could be found for breaking rock. However, no such practical means are now available. Wet drilling does accomplish this to a certain extent by laying the dust the instant it is formed, and several different types of drills are now available. The more important of these are: (a) Standard water-type drill, putting both water and air down the drill steel; (b) vented water-type drills when water and a small amount of air are directed down the drill steel; (c) drills vented with a special tight connection between the tube and drill steel; (d) standard solid piston-type drills when no axial hole is striking the end of the shank. This uses a separate water box to push all water at pressure and no air down the steel; (e) any of these wet drills in addition could use soap solutions or other chemical substances to aid the water in wetting and laying the dust; (f) also any of these types of drills are considerably improved by providing a suitable number of blows of proper force and correct speed of rotation to give maximum amount of large-size chips in the cutting.

2. Provide a clean supply of air for breathing purposes. This is accomplished for underground work with certain types of respirators. That is, respirators provided with reducing air line or to a separate supply of low-pressure air with intake brought in from the surface. Also respirators of the filter type with renewable or cleanable filter elements on each man are sometimes found effective.

3. Ventilate to change the general air rapidly enough to keep the dust content in the air to a suitable low figure.

4. Control the dust at the source. This can be accomplished by either general or direct collection probably considered the most effective and practical method. (a) General collection of the dust consists of dust collectors in the approximate vicinity of the source of dust and pneumatically conveying the dust-laden air to large filters, then discharging the clean air back into the working area, using either mechanical filters or electric precipitation; (b) direct collection of dust means collecting all of the dust at the point of discharge into the work area such as at the collar of the drillhole and depositing it in suitable containers.

Two methods now considered are the dusttight connection between the rock face drill steel and the suction tubing and a loose mechanical fit between the rock face steel and the suction tubing. The first mentioned or tight connection necessitates dry drilling with enough air forced down the drill to clean the hole and offers mechanical difficulties to maintain the tight fits on the uneven surfaces encountered in rock-drilling. It also has the advantage that this type of dust collection can be used with either wet or dry drilling. The amount of suction necessary to pick up the dust particles will not detract the flow of muck and water from the drillhole, but will effectively pick up all the dust and fine particles. Wet drilling is often considered necessary on account of the nature of the rock and, together with a dust-collecting suction device, is required where very low dust counts are to be obtained, particularly in a confined working place with limited ventilation.

However, dry drilling can be used underground with this type of dust collection (where general ventilation is good) or for outdoor work and low dust counts maintained.

Dust Control in the Foundry Industry

The interest of the foundry industry in silicosis is indicated by three papers, entitled "The Dust Problem in the Foundry Industry", "Legal Aspects and Employer Responsibility", and "Enlistment of Foreman and Worker Interest in Keeping a Clean and Orderly Foundry", delivered at the convention of the American Foundrymen's Association in 1933. In the first paper mentioned Meiter (296) stated that silicosis may be prevented in general, by reduction of dust to a safe concentration and by initial and periodic medical examinations. Dusty plants can be cleaned thoroughly, he said, by the following methods: Use of water under pressure; compressed-air blowing; use of brushes and brooms; vacuum-cleaning; and use of air and water under pressure. He recommended elimination of dust at the source, which is of great importance, by the following procedures: Good housekeeping methods; elimination of bad practices; maintenance of equipment in a dusttight condition; use of suction systems; isolation of dusty processes; special ventilation arrangements for special processes; and supplying protective devices to workers. He said that the desired results could not be obtained by using one of these methods; the particular combination which will be successful in one plant may not be in another. These methods, therefore, must be adapted to the specific problem that arises in different groups. Special attention was drawn to the method of abrasive-cleaning and the suggestion made that the efficiency of these methods should be tested periodically by screen-sampling. Meiter (296) stated that dust problems in industry can be controlled by proper supervision and education, but that it is essential that both employers and employees realize the importance of the problems and the necessity for combined efforts in reaching their solution.

From an investigation of health hazards in the foundry industry at the request of the Wisconsin Manufacturers' Association, McConnell and Fehnel (102) concluded that, although foundrywork at present may be considered a hazardous occupation, there are available well-designed equipment and protective devices which, if used and maintained, will prevent undue exposure of foundrymen to hazards injurious to health. They found that the usual ventilation of foundries is by windows. A system of forced draft, either for general ventilation or for the ventilation of individual rooms, sometimes is used. General ventilation is supplemented, as a rule, by ventilating hoods at specific points. The ventilation of foundries, so far as supplying pure air for breathing is concerned, is quite difficult on account of the smoke, fumes, and dust incident to foundrywork. Where these can be collected and exhausted at the point of origin the problem of their control is simplified, but the investigators state that unfortunately they cannot always be so controlled. They found that the introduction of new methods, new apparatus, and new protective measures has greatly ameliorated the atmosphere in foundries. Mechanical cleaning of castings in conjunction with suitable exhausts, use of tumbling operations and dusttight sand-blast rooms, hydraulic washing of castings, and provision of positive air-pressure helmets for workers engaged in sand-blasting are all measures designed to control the health hazards resulting from dust inhalation. Certain types of foundrywork must be done by the older methods, particularly in connection with large castings where production is too infrequent to warrant the expense of sand-blast equipment or where the size or character of their cores will not admit the use of sand-blast equipment. However, it was found that most of the dust incident to foundrywork results from defective equipment and lack of proper maintenance.

The health hazard from the inhalation of foundry dust results chiefly from three foundry operations (102): Sand conditioning and conveying, shake-out operations, and cleaning operations. Even when sand conditioning and conveying reduce to a minimum the distance the raw materials and sand are conveyed, the dusts created by these operations are distributed throughout the entire foundry. Marked improvement as regards dustiness would be noticeable if these operations were carried out in a separate department completely isolated from the foundry proper, and considerable dust could be confined by enclosing the sand conveyors. Shake-out operations raise clouds of fine silica dust which penetrate the entire foundry atmosphere and expose practically every worker to the dust. If the heavy castings were shaken out in a separate room fewer workmen would be exposed to the dust; with small castings the shaking-out can be done over a grate attached to an exhaust or in a separate room. If the operation was begun at the end of the working period the least number of workers would be exposed to the resulting dust, and enough time would elapse for the dust to settle before the next working day was begun. Castings sometimes are chipped, ground, and sand-blasted in a separate department, but it is common practice to conduct such operations at almost any convenient location in the foundry proper. Hoods and exhausts for trapping dust arising from grinding wheels, mechanical maintenance of a good type of sand-blast cabinet, and use of an efficient type of respirator by the operators will aid greatly in safe-guarding the workers.

Methods of Control in Granite Industry

Bloomfield's (297) study of the efficiency of dust-removal systems in two modern granite-cutting plants revealed that graniteworkers are exposed to high injurious dust (containing about 35 percent quartz) of a potentially dangerous size (virtually all the dust examined was less than 10 microns in diameter). Tests showed that the systems of dust removal in use at these plants, if maintained and used properly, can keep the dust concentration below 10 million particles per cubic foot of air. It was observed during the course of the investigation that many of the hand pneumatic-tool operators did not use the exhaust pipes furnished them; they permitted the suction hose to hang close to the ground so that pieces of granite were picked up by the exhaust and soon clogged the trap next to the metal dust; such practice obviously results in a diminution of the exhaust velocity at the working surface and an increase in the amount of dust in the air of the plant. It was noticed also that the suction devices in use with the surface cutting machines often were not used at maximum efficiency; the adjustable hoods were lifted too high from the stone, so that much of the dust generated in surface cutting escaped into the room instead of being removed through the exhaust hood. Many surface cutters either blew dust off with the compressed-air supply or brushed it off the stone without first wetting the stone with water. One of the most common abuses practiced by granite workers is blowing dust off a stone with the exhaust port of the hand pneumatic hammer. Carvers and letterers, particularly, claim it is necessary to resort to such means to remove the fine dust from the small crevices in the design being carved on the stone. In testing the amount of additional dust created by such practice it was found that a carver who blew the dust off the stone twice every minute produced 39 million particles per cubic foot of air. When he did not remove the dust by blowing it off with compressed air 29 million particles per cubic foot of air were produced.

In addition to observing certain precautions in the use of suction devices Bloomfield (297) stated that the study indicated considerable improvement in the maintenance of these systems and recommended that each plant delegate some man familiar with the ventilation system to inspect the various dust-removal devices weekly to determine whether or not pipes are clogged by granite chips and to see that all dust traps are kept free of excessive material and that leaks and imperfections in the ventilating pipes are repaired. Determination of air velocities at the surface of exhaust hoods by a vane anemometer would indicate whether each dust-removal device is functioning properly.

According to Smith (298) stonecutting is done in some 200 plants in and about New York City; most of these are small, each employing an average of less than a dozen men. In normal times work is steady and done partly in the open, the shed as a rule being open on at least one side. Conditions of work thus differ from those in some States where more severe winters force work to be done mostly in enclosed sheds. Many employers about New York City therefore believe that stonecutting in this vicinity is less harmful than in New England; however, studies in two representative stoneyards showed that dust counts exceeded limits of safety in all operations except machine polishing and sawing, and examination of 125 granite cutters in these yards revealed evidence of silicosis in 78 (62 percent) of the group examined, 33 percent being in advanced stages. Smith states that this serious hazard can be controlled by the well-known methods of local exhaust ventilation, direct protection of workers by masks, and good housekeeping, if there is a will to do so. She refers to the system of control (local exhaust ventilation) devised by Hatch, Drinker, and Choate (299), which has demonstrated its ability to maintain low dust concentrations in a large, entirely enclosed stoneyard. She also calls attention (298) to the fact that the cost of such equipment is not prohibitive, and its principles do not differ from the well-known principle of exhaust ventilation wherever applied; however, the method requires a certain amount of intelligent cooperation from the worker to attain the best results, and the employer himself should be interested and alert. Next to exhaust ventilation and direct protection by masks, good housekeeping is considered essential in controlling the dust hazard. This heading covers proper maintenance of equipment and the avoidance of unnecessary dust exposure that results from ill-considered arrangements. As example of the latter, Smith (298) cites one

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of the yards investigated; here sand was reconditioned by screening adjacent to the sand-blast cabinet, so that a number of nearby workers were exposed to the dust created thereby. As a result of poor maintenance and housekeeping, the sand-blast cabinets leaked, and dust exhausted from the surfacing machines under certain conditions blew back into the yard. As in the care of masks, attention to such details must be the business of somebody who understands the hazard and wants to control it.

Beyer (295) states that for self-preservation plants in the dusty industries must begin a comprehensive program of improvement immediately that will at least check the development of new cases of industrial disease. He mentions the following important points confronting plant managers who are struggling with this problem:

> In general, the most reliable way to correct a dust hazard is to install exhaust equipment that will capture the dust at the point where it is generated. This has been worked out very effectively for such equipment as grinding and buffing wheels.
>
> Unfortunately a complete system of dust-collecting and separating for a large department costs a lot of money--more than many plants feel they can possibly afford under present business conditions.
>
> For such cases there may be other alternatives or temporary expedients that will at least tide matters over until improved business conditions warrant the installation of a permanent dust-removal system.
>
> For instance, the manager of a plant recently visited by the writer stated that they had already spent $80,000 in exhaust equipment and had not yet fully solved the dust problem. In this industry the use of oil which has been sprayed on the material in some cases in the past to improve its handling in the machinery and processes offers a promising solution of of the dust problem. Dust counts in some plants using the oil show reductions of 90 percent or more in millions of particles per cubic foot, and if further tests corroborate these results it offers a simple and comparatively inexpensive method of correcting the dust hazard in one industry.
>
> In other operations, such as the shaking out of foundry castings, it may be possible to do this work at night, by men who are protected by respirators, and thus eliminate a common exposure to employees engaged in other operations in the same room. The use of enclosed mechanical conveyors and material conveyors and material handling systems, properly exhausted, instead of the old individual hand methods where the workers were brought into close contact with dusty substances, offers a solution in other cases.
>
> The treasurer of one concern with whom I recently discussed the hazard of his foundry said, "Maybe we have the answer right here", and he brought out the design of a machine which was fabricated entirely from sheets, plate angles, and other structural shapes, riveted and welded together, which would entirely eliminate the castings of which it was largely composed in the past.

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Where the dusty work is in a permanent location and too great freedom of movement is not required the air-fed respirator may give satisfactory results. For cases of temporary dust exposure, as for sweeping and cleaning up dust, the improved types of filter respirators may be adequate. In some cases substitutes may be found for the substance causing the trouble. ***.

The use of water to overcome dust hazards is one of the first suggestions that is usually made. I recently tried to explain this problem to an industrial manager and, after telling him that the dust which causes the trouble is less than 10 microns in size, a micron being about 1/25,000th of an inch, and being encouraged by his nods which seemed to indicate that he was following my explanation perfectly, I was a little disconcerted at the end to have him say, "Why can't you get rid of those microns by washing the air?" Apparently after all my efforts he still thought a micron was something like a microbe!

Where exhaust equipment is installed poor maintenance of these systems whereby their value is reduced or entirely vitiated is altogether too common. An inquiry in a plant recently as to how the dust-filtering apparatus was working brought the reply, "Fine--we haven't had to even look at it for 6 years!" When we climbed a ladder to the roof to see this miraculous equipment a touch on the screens shook a pailful of dust from the "clean" side of the separator. ***.

And so, to summarize the results of this brief survey of the mechanical control of occupational disease hazards, it is the opinion of the writer that chiefly in this direction lies safety from some of the most serious diseases, if one also includes rearrangement of the processes under "mechanical control", in contrast with the "medical control."

While agreeing that medical supervision of new prospects for employment is of primary importance, in order to prevent placing new employees who have some physical impairment in a position where they will quickly break down as a result of the work hazard, and granting the value of medical follow-up of employees subjected to exposures such as lead and benzol, which bring about a temporary condition that may be chacked by medical supervision and a change of occupation, it seems evident that in the most serious industrial disease hazard, that of exposure to silica dust, chief dependence must be placed on elimination or control of the dust.

Section 4. - Medical Control in the Prevention of Dust Diseases

If the problem of dust control is to be solved engineers and doctors must cooperate with each other as well as with management and labor. In an article entitled, "Health and the Engineer", Whipple (300) in 1918 called attention to the unique opportunity of engineers to become a great social force in bringing about harmony between work and workers and improving working and living conditions of the workers. He did not feel justified in saying that such work had been entirely neglected but that health-protective measures, provision for housing workmen, installation of safety devices, and welfare work of many kinds had not been done as a matter of course but rather by compulsi of law or by the benevolence or patronage of employers. He also criticized the laboring people because they did not appreciate these measures as great factors in their problem, their chief aim being more pay for less work. He said that engineers fill an intermediate position between the employers and the employees, and to do this properly they needed to broaden their idea of efficiency from that of the most work for the least cost to include benefit to constructing laborers as they build and to the workers who are to use the constructed plant, in this, the hygienists must cooperate and show engineers what to do. He stressed the need of cooperation among all who have to do with human health. Zangger (301) observed lack of cooperation and even interference in each other's work among technicians and medical men; there shou be no sharp line of distinction in the knowledge of protection against industrial diseases among doctors and technicians--each should have some knowledge of the other's work.

The literature contains comparatively little information on medical control of dust diseases, except for the work done on the Rand in South Africa this lack may be due in part to the attitude formerly taken by the medical profession toward industrial work. Davis (302) deplored this attitude as late as 1920, as shown by the following:

> The best of the medical profession have in the past looked askance at industrial work, because of lack of system and business methods in the average doctor's work. Most doctors are individualists in thought and action, and there is a generally prevailing idea that industrial medicine is performed by "down-and-out" doctors, at contract rates enforced by heartless corporations.
>
> The profession is changing its attitude as its members see what can be accomplished by organization and group practice as exemplified and demonstrated by various organizations now existent.
>
> On the side of business there is the awakening sense that cheap and inferior medical work is not satisfactory in any particular and is often disastrous and that the best medical talent should be procured. This presages the getting together of the best in medicine and the best in industry, to their mutual benefit.

In a recent discussion in England of the apparently sudden development of silicosis among the South Wales coal miners Moss (303) said that he could not imagine, somehow, that doctors in the country as a whole would have failed in the past to diagnose such a serious disability had it been prevalent. As mining conditions are much the same as in the past, he could not conceive that conditions could be worse on the whole, and yet all at once this disease was said to be springing up in South Wales. He wondered whether the increased liability of the South Wales miner to lung trouble was not due to a lowered standard of living there, compared with the rest of the country, and had no reference to the conditions in the mines.

The above statement calls to mind the conclusion reached by the Royal Commissioners appointed in England in 1862 (9) that the influence of dust was subsidiary to many other adverse conditions in spite of the evidence of the miners themselves that dust was far worse than anything else with which they had to contend.

State compensation laws compelling medical and surgical treatment for injured workers emphasized the value of medical service in industry, and the growing realization of the menace--economical as well as physiological--of dust diseases in industry has been attracting the attention of outstanding members of the medical profession; the qualifications required for successfully coping with such industrial diseases are infinitely higher than those formerly considered sufficient.

Lauffer (304) has called attention to the health hazards within the industries, which industrial initiative should control; within the communities, which coordination of industrial and community health service can control; and within the scope of the individual, which require his personal initiative to combat successfully.

Physical Examination of employees

Probably the most important weapon in the medical control of dust diseases is the physical examination of the worker. Selby (305) described physical examination as the means whereby physicians acquire the information they deem essential to the procurement and maintenance of healthy, physically competent working forces. It is the basis of medical knowledge in industry and is fundamental to the successful practice of industrial medicine. The scope of the examination should be broad enough to enable physicians to gather the requisite information. It should therefore uncover defects and diseases that render employment hazardous to him who seeks it or to his fellowworker; it should uncover imperfections that contribute to inefficiency and diseases and substandard health conditions; in short, it should divulge the true condition.

Regarding the impression that the employment of healthy, physically competent workmen may imply the rejection of those who are not, Selby (305) said that the latter need not be rejected outright and deprived of the privilege of gainful occupation, as there are positions in virtually every plant of reasonable size that persons of varying substandard conditions of health and body can fill efficiently, to the profit of their employers and themselves. Only the manifestly unfit and the victims of communicable disease should be rejected--with rejection the last resort.

According to Burlingame (306) safeguarding the health of the employee is the one interest the worker has in common with the employer. From a study of the development of industrial relationships and contacts through a community health and tuberculosis demonstration over a period of years Armstrong (307) concluded that medical and nursing facilities in industry can be used to full advantage only if they are operated in close cooperation with the labor groups concerned. These facilities must be used with the primary object of fitting the man to the job, not as a device for rigid elimination of the unfit from industry. It must be recognized, however, that through the adaptation (or possibly elimination) of a few will come the protection of many.

In outlining the program which he followed in examining workers in dusty trades Sanders (308) said that the purpose of the examination was not so much to eliminate the unfit as to place workers in positions in which they seemed best suited. He emphasized that during the course of such an examination the worker's viewpoint on safety might be changed materially by taking advantage of the personal contact to inform his regarding the purpose of the examination program and what he himself could do to curb dust dissemination.

A large automobile-manufacturing company gives a preemployment medical examination and assigns a new employee to work that fits his condition. According to Cameron (309), disability does not necessarily bar him from a job, as is borne out by the fact that 20 percent of the workmen (12,000 in all) employed by this company are in the physically disabled class--some are blind, some deformed, and some are not very strong. Each man's work is selected to fit his case; tuberculous men have sheltered places in the open air, and by a system of medical transfers jobs may be changed at any time for reasons of health.

Britton (310) states that when a comprehensive plan for such service has been worked out as a part of the whole industrial-relations program a medical department in an industrial unit can be of greatest service both to management and employees and can and should be one of the strongest influences in cementing a cordial relation between industrial employees and management. However, such a plan requires a staff of the highest caliber, an adequate place in which the staff can work, and modern facilities for making accurate observations. This organization and equipment should be used constantly to assist in determining any industrial factor affecting the health of industrial employees.

At the meeting of the National Safety Congress in 1934 Adams (311) strongly urged employers to conduct periodical physical examinations but cautioned them against conducting these examinations with the sole idea of weeding out the unfit. "The chief value of such examinations," he said, "and for that matter the chief value of a medical department, is to fit each industrial worker to a job according to his ability to perform it without injury to himself or to his fellowworkers and with profit to himself and his employer. A byproduct of the examination is the record of existing disabilities which may be valuable in the prevention of subsequent false claims of disability from previous handicaps."

The first well-known, extensive, long-time use of the physical examination in connection with the prevention of dust disease was in the control of silicosis in South African gold mines.

All medical examinations of South African miners are conducted or controlled by the Miners' Phthisis Medical Bureau, a central body of whole-time government medical officials created in 1916. With regard to European miners the main functions of the Bureau have been:

1. To conduct an "initial examination" of all new recruits for the industry;

2. To conduct a "periodical examination" of each working European miner once every 6 months in order to secure the early detection of all cases of silicosis or tuberculosis which arise amongst the working miners;

3. To conduct a "benefits examination" of all miners or ex-miners who claim compensation in respect of the presence or suspected presence of silicosis or tuberculosis; and

4. To decide from the medical standpoint upon the claims of dependents of deceased beneficiaries.

The mine natives are given three medical examinations--a preliminary sifting in the recruiting area, a principal examination at the Witwatersrand Native Labor Association's depot in Johannesburg, and a supplementary examination by the mine medical officers. The aim of the periodical examination conducted or controlled by the Miners' Phthisis Bureau is to detect all cases of simple silicosis, tuberculosis with silicosis, or simple tuberculosis among the working miners and mine natives. The following summary indicates some of the results attained by these examinations (81):

> A very important result of the initial examination in the case of European miners has been the gradual introduction since 1916 into the general body of working miners of a group of men of specially selected physique, whom we call the "new Rand miners" and who now number over 8,300, or 54 percent, of the whole body. ***.
>
> From the purely preventive aspect the most important consequence of the periodical examination is the permanent removal from underground work of persons found to be suffering from tuberculosis or tuberculosis with silicosis, who are thereby prevented from remaining as potential sources of dissemination of infection. The number of cases of these conditions detected amongst European miners has fallen steadily during the past 10 years and does not now constitute a serious menace.
>
> The preventive aspect of the periodical examination is of more importance as it affects the native mineworkers. ***.
>
> The result of the examinations of mine natives discloses that simple tuberculosis and tuberculosis with silicosis taken together are decidedly more prevalent amongst them than amongst the European working miners. The reverse is true of simple silicosis. ***. The number of cases detected annually is considerable, and, so far as underground conditions are concerned, it is from the mine native that the menace of tuberculous infection arises both in the production of cases of frank tuberculosis and in that of early infective silicosis amongst European and native employees alike. Hence the necessity of continuing the campaign to reduce all possible sources of tuberculous infection in the mining population to the fullest practicable extent. ***.
>
> From the years 1917 to 1920 the incidence averaged 3.5 percent, but the returns for these years were inflated by the inclusion of a considerable

number of "accumulated" cases of early silicosis which became compensatable as "ante-primary-stage" cases in 1919 to 1920. ***.

But the further drop which has since occurred to a figure of 1.76 percent in 1928 to 1929 is even more satisfactory. It represents a genuine improvement because it has been effected in the face of a continued increase in the number of older miners at work. ***.

The most striking evidence of improvement is seen in the returns for the specially selected body of men who have entered the industry since 1916 and whom we have termed the "new Rand miners." These men now number over 8,300 and are increasing year by year. Now whereas in the period from 1920 to 1928 the attack rate for silicosis amongst all miners who were working in their tenth year of service was 5 percent, amongst the "new Rand miners" working in their tenth year of service in 1928-29 it was only 1.3 percent. Part of this effect is certainly due to the better stamp of man of which the "new Rand miners" are composed. But if we allow an equal share to that factor this result is still remarkable. One cannot indeed anticipate that rates of this low order will continue when the "new Rand miners" enter the later periods of service, but there is no reason to suppose that they will even then reach the relatively high figures which the older miners have hitherto shown.

The second most extensive long-time use of the physical examination in connection with the employment and placing of workers in the mining industry was undoubtedly that in the Picher district in the United States (88,89) with the primary purpose of reducing the incidence of silicosis and tuberculosis among the miners and safeguarding their general health and that of their families. The employees voluntarily submitted themselves for examination with the understanding that all miners employed at the time, except those having tuberculosis and advanced silicosis, would be allowed to continue working. Men suffering with infectious diseases in the active stage were suspended until noninfectious. The examinations, continued annually for 5 years (1927-32), revealed that many of the men at work and applying for work had one or more diseases or physical defects; many had serious and in some instances contagious diseases. In all 44.03 percent had one or more diseases or defects considered serious enough to bear directly upon their work, compensation risk, or life expectancy. Certain physical defects and diseases were revealed as apparently predisposing causes of silicosis. So few cases of nasal obstruction were found that no definite conclusion could be drawn, but apparently both silicosis and tuberculosis showed a slight increase in men with this defect. This observation is confirmed by reports of a test made in Germany by Lehmann (312), who examined 426 noses; 241 of the miners were ill with lung troubles, and 185 were well. The noses were tested by blowing into them air laden with a fixed amount of dust and allowing the air to issue from the mouth while the breath was held. The dust content of this air was measured, and the percentage of the original content filtered out by the nose was determined; the healthy miners prevailed among the high percentages, the affected among the low percentages. Lehmann (312) recommends that no man be admitted to a dusty job unless he can pass such a nose test. His discussion of the results follows:

In all occupations in which a silicosis hazard exists it has been observed that individual susceptibility varies greatly. Whereas many workers become ill after only 2 or 3 years in a dusty occupation, others show only a trace or else no lung changes at all. The studies described permit us to utilize an important (and perhaps the most important) factor of this individual susceptibility. The figures given indicate that the silicotic susceptibility of workers with poor nasal filtration is much greater than that of men with good nasal filters. Consequently it seems to us logical that jobs with a silicosis hazard should be held only by men with good nasal filters.

We do not know today to what extent nasal filtration can change in the course of several years. It is probable that, in connection with atrophic disturbances to the mucous membrane, a general lowering of the filtering action will result. It would, therefore, seem advisable to repeat the tests yearly. Then any worker who showed a general lowering of nasal filtering power and had thereby acquired an increased susceptibility to silicosis should be removed from his dusty job and placed elsewhere. The so-called "mouth breathers" are an especially bad risk and should be excluded from any task involving exposure to dust rich in silica.

According to Safety Engineering (313), the nose is a perfect apparatus for dust filtration to a certain extent; if the nasal organ is functioning as Nature intended it will trap a large proportion of the dust breathed and keep the lungs free and in good working order.

Tillson (124) has suggested that certain measures might be taken to increase the natural defensive reactions of the respiratory organs. He elaborates the idea in the following statement:

> As part of Nature's defense against the intrusion of dust in the system, a ciliated epithelium is provided as a lining of all air passages except the upper part of the nares (the nostrils), lower part of pharynx (the $4\frac{1}{2}$-inch long alimentary and respiratory canal to the esophagus and trachea terminal), the bronchioles, and finally, the pulmonary alveoli.
>
> This epithelial structure is a layer of more or less columnar cells, on the exposed surface of each of which is a bunch of fine, tapering filaments with tubular channels opening at the tips. These cilia (hairlike processes) move in such a waving fashion as to produce a flow outward of the fluid which bathes them. They make a rapid stroke in the direction in which the action is to be effective and a slow return stroke; also, all cilia attached to any one cell or row of cells acts synchronously; furthermore, any individual cell begins its effective stroke slightly later than the cell lying internal to it. In this way a progressive wave motion is produced to carry toward the exterior dust or other extraneous matter which becomes entangled in the mucus that is deposited in the ciliated surface by numerous glands.
>
> Activity of the cilia is modified by almost any factor which affects protoplasmic activity, such as concentrations of oxygen, carbon dioxide,

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hydrogen ions, and various salts; also, increase of temperature up to a critical value causes increased activity. But especially, the rhythm and rate are increased by mechanical loading from placing a particle on the mucus-covered tip of a cilia; and the hypothesis is advanced that the blockage of the tip opening of a blind tube increases the liquid pressure in the same and with it the increase of the flagellating activity of the cilia above their normal frequency of approximately 10 waves per second.

All of these factors are of interest when considering the preventive measures which man may devise to cooperate with and stimulate natural preventive functions. For example, if dust particles had the same sign of electric charge as the phagocytes, they would repel them and not be ingested to produce toxic effects. But could elimination be provided in some other manner? A deficiency of mucus or cilia activity might be overcome by artificial means and a more rapid and complete ejection of dust particles thereby be accomplished. A suitable electric polarization of dust particles might assure their repulsion of attraction to the cilia with corresponding ejection. Establishment of a proper acidity (pH value) in the respiratory tract might be effective.

The introduction of a hydrophillic substance with an effective surface (that is, one with an area large enough to accommodate the ends of chain-type molecules which may be held end-on to it) can initiate the process of a clot formation by offering plasma-wettable surfaces to which certain blood cells (as the thigmocytes) may adhere and over which they will spread to produce their rupture and liberation of their thrombin content to react with fibrinogen and produce a clot of fibrin. Powdered glass, quartz particles, bubbles of carbon dioxide gas, and pieces of tissue provide such surfaces and can cause that serious pathology called thrombosis, so often fatal in its results. Again, still another danger is created by the injection of certain mineral dusts into the systems.

Diseased conditions of the mouth (pyorrhea and missing and decayed teeth) may have caused the gastrointestinal symptoms which were the most common subjective symptoms mentioned by the silicotics in the Picher district.

The examinations at Picher indicate that syphilis apparently is closely related to silicosis, silicosis plus tuberculosis, and tuberculosis. Close correlation of the incidence of syphilis with uncomplicated silicosis indicates that syphilis may be a predisposing cause, and clinical observation leads to the belief that silicosis runs a more rapid course in syphilitics.

The Picher investigation also revealed that the percentage of uncomplicated tuberculous cases increased with each age group (between 60 and 69 years), but this finding does not agree with the known fact that the disease is more common in early adult life. The condition at Picher probably is due to the fact that many persons with arrested tuberculosis work for a time in the mines after returning from the high, dry climate of the West. Clinical experience has shown that these cases soon become active and often run a rapidly fatal course. One percent of all industrial workers are said to have tuberculous lesions in their lungs (314), indicating the advisability of examining applicants for work in dusty trades since such tuberculous lesions under unfavorable

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conditions predispose to the development of tuberculosis in a year or less. An X-ray examination would reveal this condition, and the prospective employer would know definitely which workers would be unsuited to exposures that would favor the development of tuberculosis; those affected would thus be saved from exacerbation of their condition and also their coworkers from infection. In connection with the advisability of preemployment examinations the following instance mentioned by McCord (315) is interesting:

> Lately I have had opportunity to examine well-made X-ray films of applicants for work, without admitted previous exposure in industry. These persons were found to live and drive on dusty country roads made of flint. Approximately 50 percent of these young adults presented sufficient involvement in their films to be rated as "suspicious" in relation to pneumoconiosis. Given a few months exposure in a foundry any one might hold himself eligible for claims against his employer alleging dust lung disease.

According to Flinn (316), the steady rise in the rate of attacks of influenza in cementworkers would seem to indicate that the mucous membrane of the respiratory tract has been injured to the extent of lowering body resistance to such attacks; if the mobility rate of the lungs of workers in the dusty trades were tested it probably would be found to decrease with the length of exposure at a rate unaccounted for by the decrease due to age. He found that after working 8 years in cement men showed a definitely lower vital capacity than workers in 10 other occupations or than men who had worked less than 2 years in cement; army regulations discard a man 68 inches tall as a tuberculosis prospect if he shows less than 2 inches of mobility. This would indicate the value of periodical examinations of workers in dusty industries to determine whether the vital capacity is being affected by the occupation; Flinn points out that only by studying the individual himself from time to time can any conclusion be reached in this matter.

The same idea was expressed in 1916 in the General Report of the Miners' Phthisis Prevention Committee (317):

> That man who is best suited for underground work is one with a good and sound physique and with a good reserve of respiratory capacity. A man of poor physique may be sound in the sense that he is not actually diseased, but he has commonly a low power of resistance to infection, and if he has a poor respiratory capacity he has so much the less available respiratory reserve.
>
> Age is also of importance. We doubt the economic wisdom of accepting for underground work for the first time any man of over 45 years of age unless his physique is unexceptionable. There is normally in persons round about 50 years and over a tendency to an increasing reduction in the expansile power of the chest wall, and a proneness to bronchitis and emphysema. Dr. Watt has called attention to the fact that there is apt to be an increase in the amount of fibrous tissue in the lungs as age advances.

> These facts are of importance, because a man with a good chest and a good reserve can carry, without inconvenience or loss of health, an amount of fibrosis which might seriously affect one with a poor reserve, or a chest becoming rigid through age.
>
> All persons who have signs of a tuberculous taint, even if it be latent should be rigorously excluded.
>
> Cases in which one or other of these factors have been present are familiar to those who have to examine claimants for compensation under the Miners' phthisis Act, and it is noticeable that, in many such cases, the duration of underground service has been comparatively short.
>
> We would recommend that a uniform standard in regard to the degree of physical fitness required of a man on first application for underground work should be arrived at, and a simple examination form should be drawn up for use at such examinations. Such a policy would be useful also in detecting physical defects or the results of previous injuries, which would be of importance for identification and, incidentally, of value medicolegally.
>
> We would suggest that examination of all men applying for the first time to undertake underground work should be conducted by a central examining board, an arrangement which would conduce to uniformity and relieve mine medical officers of a duty which is often unpleasant when applicants have to be rejected.

The results of the industrial survey made by McCann (266) in Rochester, N.Y., in connection with a so-called "silicosis racket" revealed dangerous quantities of dust in the air of a number of plants; but the most disturbing result was the lung conditions revealed by the X-ray examinations. Only about 30 percent of the lungs examined could be considered normal; almost invariably the possessor of the normal lungs was a machinist, watchman, officeworker, or a very new and young employee. McCann (266) states, however, that it must not be inferred that 70 percent of the employees in the industries surveyed have silicosis or pneumoconiosis; about 40 percent of the total exhibited pathological changes in the lungs which did not in the least resemble those of silicosis or pneumoconiosis. This group comprised all sorts of abnormalities such as evidences of chronic nontuberculous infections of the lower lobes, bronchiectasis pleural adhesions, and the fibrosis of heart disease accompanied by abnormal shadows of the heart and large vessels. A certain amount of adult tuberculosis some healed, some apparently latent, and some undoubtedly active—was found. In fact, this large group showed all the common types of pulmonary disease that could be found in any group of similar ages. It included all persons whose lungs showed a diffuse reticular fibrosis with increased density of the shadows at the root of the lungs; all such cases were classes as suspected pneumoconiosis. If the reticular markings tended to agglutinate or suggested nodular mottling the diagnosis was changed to "probably early pneumoconiosis"; if the nodular mottling was clear-cut a definite diagnosis of pneumoconiosis was made, in spite of McCann's firm belief that this diagnosis should never be made on the basis of history and X-ray examination alone, because employees whose chest films revealed this condition could sue for damages with great probability of success in a trial by jury.

Ogden (313) recommends a very complete history of all new employees because he claims that malnutrition of idle workers during the depression has increased susceptibility to silicosis and other industrial diseases.

McConnell (319) believes that thorough physical examination at the time of employment and at regular periods thereafter is the best method of eliminating diseases caused by dust in industrial establishments. The effectiveness of dust-control measures in preventing dust diseases can be determined only by careful physical examination of the worker so exposed under guidance of competent medical supervision. He states that the benefits that accrue to the employer and employee alike as a result of physical examination of all applicants for employment, as well as periodical examination of those already at work, would indicate very careful consideration by industry of a program for control of sickness. Such procedure protects the employer from engaging an applicant already physically or mentally impaired, who later may claim disability for his condition even though it was not associated with employment or was contracted during a period previous thereto. The applicant's physical and mental condition is thus established, and by keeping records of his subsequent illnesses and accidents the question of responsibility for injuries and sickness incurred during employment never need arise. He also states:

> The diagnosis of the diseases resulting from industrial hazards and the extent of disability incurred obviously should be entrusted to medical men specially qualified for this work with facilities for adequate radiological examinations. Disputed cases should be referred to a board composed of trained personnel capable of coordinating the medical, radiological, and pathological examinations as well as the results of scientific investigations. The action of such a board of specialists should be final.

McConnell (319) outlines a plan for medical control of all phases of the dust hazard as follows:

1. Establishment of a medical department adequately equipped.
2. Routine examination of all applicants for employment.
3. Rating and placement of applicants.
4. Periodical physical examinations.
5. Provision for the disabled.

Bateman (270) states that next to ventilation and the laying of dust the most important measure in the prevention of silicosis is careful selection of the type of men to be allowed to work in the mining industry. This requires a rigid initial examination, which should include a complete physical examination and X-ray. Men with a chest indicating susceptibility to tuberculosis and silicosis could thus be eliminated. Uncomplicated silicosis is not a big problem, but silicosis and tuberculosis combined represent a very real problem, and particular attention, he believes, should be paid to withdrawal from the mining industry of men with tuberculosis. He also recommends that employees' living quarters be supervised to see that the men are not exposed to tuberculosis at home.

Clinical and X-Ray Examinations

The studies conducted at the Picher Clinic (38) included collection of personal data such as age, marital status, and contact in the home with tuberculous patients; past history of disease; occupational history, including past and present occupations, total years worked, and years worked in dusty operations; present history detailing subjective symptoms experienced by the examinees; physical examination, including such objective data as appearance, development, weight, height, pulse rate, respiration, blood pressure, and condition of eyes, ears, nose, throat, skin, chest, heart, and other organs; X-ray examination of the chest; and laboratory examination, including blood count, Wassermann test, and microscopic findings.

According to McNally and Bergman (320), a history of the exact occupation and exposure of each workman in the silica-containing dust, a complete physical examination with the symptoms, and X-ray pictures are absolutely necessary. They state:

> Just as in the case of bronchitis, the connection between the disease and dust inhalation must depend upon an intimate knowledge of the occupation followed, of the exposure to dust, and of the mortality prevalent in that occupation. A correct diagnosis is of importance because, with the known tendency to a fatal termination, every case from its onset however apparently slight must be considered serious and treated accordingly.

Fisher (321) suggested that the cases of silicosis in the South Wales anthracite fields might be explained by the fact that the miners became chilled after the shift during the trip to the surface in cold intake air, the resulting bronchitis breaking down the natural mechanism by which dust is eliminated from the bronchial tubes and lungs. With the impairment of the dust-eliminating mechanism of the respiratory system dusts that normally are harmless either because of the rapidity with which they are removed or because of their low silica content tended to accumulate and produce fibrosis and diminished efficiency of the lungs. These facts led him to believe that the "nonindustrial" medical history of a youth who intended to work in dusty parts of a mine, such as conveyor ends, hard headings, or machine-cut faces, should be considered, as bronchitis and bronchopneumonia might facilitate the entry and obstruct the exit of fine dust particles. Fisher (321) also recommended that in view of the fact that damage to the respiratory system through bronchitis interferes with the dust-eliminating function of the lungs men who suffer from chronic cough or acute bronchitis should consult a doctor before taking up or resuming work in high dust concentrations, particularly in areas where many cases of silicosis occur.

Cook (322) stressed the vital importance of the radiological aspect:

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The many varied shadows met in the chest that so nearly simulate each other make all avenues of diagnostic aid welcome by all well-meaning and open-minded medical consultants. One sees a great many confusing shadows in many of our respiratory conditions that may be so familiar by long and careful observation that something of less importance that may be a contributor is apt to be overlooked.

An opinion based upon roentgen evidence alone is of about the same value as an opinion based upon clinical findings alone. Without a careful history both lose much of their worth. Combined with other evidence, however, it may be of great value--without a doubt it is capable of revealing changes in the lungs which cannot be demonstrated by any other method.

In difficult cases, or those in which physical signs are absent, the roentgenogram may be the confirmatory evidence upon which a diagnosis is made--and in certain well-defined cases it may give a more accurate picture of the extent and distribution of the process and in this way give aid both to the prognosis and the treatment of the case.

Unfortunately, very few roentgenologists are well-trained clinicians. It is perhaps equally unfortunate that few clinicians have sufficient knowledge in interpretation of roentgen findings.

The cooperation of both clinician and roentgenologist, or the combined use of a single investigator, will obtain better results. The most careful and painstaking history often fails to reveal some of the most profound and complicated films that are met. A scoliosis may displace the heart or great vessel and give a peculiar shadow that can easily be misinterpreted.

All examinations should be supplemented by a careful fluoroscopic examination.

It is therefore essential, before making an ultimate diagnosis, that the history be carefully studied relative to exposure, length of time, and type of exposure. Many times I have been called to see patients with definite pneumofibrosis who had never been exposed to any type of industrial hazard.

In view of the present situation, many possibilities have been opened for the questionable unemployed to remember that at some time he was employed in a semihazardous occupation. The finding of some of the many types of lymph block fibrosis--this aided by the ever-willing legal vulture--has brought many nonindustrial contracted conditions into the courts of compensation.

According to Gardner (323), the roentgen examination requires good films, expert knowledge, and experience. A tuberculosis expert reading silicosis plates would observe the pneumoconiosis signs and, after consultation and study, acquire knowledge of its type and degree. Physical signs of pulmonary infection are few and seem insignificant unless the silicosis shows complication by infection.

The following statement by Landis (324) indicates the difficulties encountered in the diagnosis of respiratory diseases among anthracite miners:

> The interesting thing is that a roentgenologist who is out of these local spheres where you see the dust cases, particularly in the second stage where it looks as though you had thrown a handful of snowflakes against the film, almost invariably makes a diagnosis of miliary tuberculosis. In the third stages they will almost invariably make a diagnosis of advanced tuberculosis. ***.
>
> So far as the complicating tuberculosis is concerned, even the shrewdest reader of X-ray plates will be deceived, very often as to whether there is a complicating tuberculosis or not in a given case, so that you are driven back in many cases, though some are perfectly obvious. There is no difficulty in telling tuberculosis superimposed, from the X-ray picture, but in many of them it gets down to the question of sputum examinations. If the sputum is consistently and repeatedly negative, you are safe in assuming you are dealing with a plain, straight case of pneumoconiosis. Perhaps in autopsy it will show a small focus which is incidental and has no bearing on the situation whatever.
>
> We have a man at the White Haven Sanitorium now who has had 4 years' experience in examining a very large number of these cases of pneumoconiosis and only within the last 6 months, in spite of the fact that he has seen so many of them, he had 1 case in which he said there was complicating tuberculosis, and repeated sputum examinations failed to establish it. Another which he said showed no evidence of tuberculosis was taken later and showed tuberculosis.

Similar difficulty is encountered in making a diagnosis by the physical examination alone. On this point Landis (324) said:

> There is another curious thing and that is that on examination of the chests of these people, from the standpoint of physical diagnosis, in spite of the fact that the X-ray film will show the most dreadful lot of changes in these lungs, from the physical signs you get next to nothing. You may not get a single, solitary thing. ***.
>
> Within the last 5 years (and I am not certain that it does not apply even today) pneumoconiosis rarely if ever figures in either morbidity or mortality results. It is buried under all sorts of guises--tuberculosis, chronic bronchitis, pleurisy, etc. Furthermore it has more of a local interest. I mean local in the sense that there are men living in localities who by no possible chance practically ever run into this condition which in other localities is extremely common.
>
> I am reminded that about 13 years ago I gave a clinic before the medical students on pneumoconiosis and didn't give the matter any particular thought until the morning, when I thought it would be an easy matter to get sufficient X-ray films from our X-ray laboratory to illustrate what I had to say. To my amazement, when it came time to get them although the

Peter Brigham Hospital had been in operation for 3 years, they had just 1 pair of X-ray films showing pneumoconiosis. That was from a Spaniard who had worked in copper mines in Chile and who had been admitted to the hospital for something else, but the pneumoconiosis had been discovered accidentally.

It so happens that this condition with me is of a monthly occurrance. For the past 25 years I have been on the visiting staff of White Haven Sanitorium which is situated on the edge of the anthracite coal fields. At the present time, and for the past 4 or 5 years, all of the cases of tuberculosis of Luzerne County are sent to that sanitorium. It doesn't make any difference whether they have tuberculosis or not, the astonishing thing is that 60 percent of the miners I sent in under the belief they had tuberculosis are suffering from plain, straight pneumoconiosis. Every time I go up there--every 2 weeks--I find committed to my service from 1 to 3 of these miners. ***.

If you were to go to Wilkes-Barre General Hospital, into the X-ray laboratory where many of these men are X-rayed as a matter of routine--where they are admitted for fracture of the leg or arm or minor disaster--men who have no respiratory symptoms at all at that time--you would be perfectly amazed and appalled at the number of them who show perfectly definite changes in the lungs.

The following technic was used in the radiographic work at the Picher Clinic (88): All radiographs were taken at a distance of 36 inches, using ½ to ¾ second of exposure, 55- to 85-kilovolt peak, at 30 milliamperes. The thickness of the chest was measured in centimeters with a pelvimeter. The kilovolt peak was regulated to compensate for varying chest thicknesses; the milliamperage, distance, and time remained the same. In chest radiography intensifying screens are a decided advantage from the standpoint of contrast, as a much lower penetration is permitted with the necessary time, distance, and milliamperage. Fifty to 100 kilovolts or more were used; most of the pictures were made under 85 kilovolts. When the work was begun the distance used was 72 inches and the exposure ½ second. Motion was so great that only a few hundred films were made at this distance. Most of the work was done at 48 inches with an exposure of 1/10 second. All electrical installations were 25-cycle, the current emanating from one large plant which supplies 200 to 300 mines. The burden on the current, even with a transformer installed at the clinic, gave such marked fluctuation that comparable pictures were obtained with great difficulty.

Pancoast and Pendergrass (325) have published two reports on the equipment required and the exact technic for the X-ray examination of important cases of silicosis. They stress emphatically the necessity for a most careful technic in such examinations and the necessity for observation of the most exact details. They describe the positions to be assumed by the patient to give the most satisfactory films and the equipment necessary for the essential exposure factors. They make the following comment:

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It is fully recognized that the above suggestions are the ideal. There are many times when it would be impossible to employ such an elaborate method of examination both because of the time and economic factors.

It is quite possible that the time will come when it will be necessary for industry to make routine roentgen examinations of the chests of all men seeking employment in dusty occupations. This must be performed adequately with the least amount of expense. It seems reasonable to believe that a careful fluoroscopic examination would exclude the presence or absence of 90 percent of tuberculous lesions. It could demonstrate silicosis at least of the nodular type. Wherever there was the least question of doubt, a single film of the chest could be exposed, and if this was inadequate steroscopic or even additional films could be made. The ideal procedure would call for at least a single film of the employee before beginning work. This would not always be possible, if, for instance, there was a demand for 200 men to be put to work at once. With careful fluoroscopic examinations, however, it would be possible to study a large number of men in a short period of time and exclude any with gross evidence of disease.

In follow-up examinations similar methods can be employed, the examiner using his best judgment as to the advisability of obtaining the film record. Each examiner should bear in mind that the fluoroscopic examination is not a tangible permanent record as are properly exposed films, and in order to protect the employee and employer one should have a permanent record. It should be borne in mind that such records (single film) would be of little or no value in case of subsequent legal claims.

The following rules and regulations dealing with the health of workers exposed to the silica-dust hazard came into force in connection with workmen's compensation (Silicosis, Acts of 1918 and 1924) in Great Britain in 1925 (326):

> All workmen employed in the industries shall be examined by one or more officers of the medical board at the prescribed intervals, and if on such examination it appears to the medical board that the workman is suffering from silicosis or tuberculosis or silicosis accompanied by tuberculosis to such a degree as to make it dangerous for him to continue work in the industries, the board shall suspend the workman from further employment in the industries and shall certify accordingly in the prescribed form.
>
> Any workman newly engaged by an employer and not excepted shall, unless he has already been examined under this scheme within the preceding 12 months, submit himself for examination by a member of the medical board or other duly appointed medical practitioner before the end of the first month of his employment or in exceptional circumstances within such extended period as the medical board may authorize; and if on such examination the workman is found to be unsuitable for work in the industries by reason of his failure to satisfy the requirements with respect to physique prescribed herein, the member of the medical board or duly appointed medical

practitioner shall suspend the workman from further employment in the industries and shall certify accordingly in the prescribed form.

For the purposes of this paragraph the requirements with respect to physique shall be as follows:

1. The chest must be at least of average development with satisfactory expansion and there must be no deformity or obstruction of the upper air passages or elsewhere which interferes with respiration;

2. There must be so signs of present or past disease of the lungs or heart; and

3. There must be no signs of present or past tuberculosis of any region.

On March 26, 1935, the Workmen's Compensation Law of North Carolina (327) was amended to include some occupational-disease features, among which were physical examinations for prospective and present employees engaged in the dusty industries, silica and asbestos industries; a medical committee to make examinations under the supervision of the industrial Commission; removal of employees in the early stages of disease; vocational training for those removed. According to Safety Engineering (327), this bill was drafted after many conferences between employers and employees. The bill includes a list of specified diseases and conditions as constituting occupational diseases within the meaning of the act.

Treatment of Silicosis

There is no cure at present known for silicosis, or at least no treatment has been discovered that prevents the progressive development of the characteristic fibrosis after it has started in the lungs. The deadly character of the disease was recognized as early as 1500 by Paracelsus (21); he mentioned in his book of miners' diseases that "the organism must be prevented from coming in contact with the metal emanations, for if the organism is once injured there is no cure."

At first it was thought that removal of the victim from further contact with dust would arrest the condition at the point of development reached when discovered. Although this may have been true in some instances apparently it is not generally so and according to Lanza (328) has not been borne out by recent experience. He states, however, that--

> The question of what to do for the silicotic patient is one of great moment, but recent experience has shown that removal from exposure and allowing the person to be up and around and not sending him to a sanitarium are probably best. Considerable research is being done in this country at Saranac Lake, the U. S. Bureau of Mines, and at Rochester; but not as much research is being done as should be when the economic importance of the present silicosis situation is properly taken into account. The importance of using specially selected medical boards cannot be overemphasized, and the successful experience of the British should be adapted in this country.

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A study by Lawson, Jackson, and Gardner (329) of the afterhistory of 17 miners who had run drills 4 or 5 years for iron ore in the Blue Ridge Mountains revealed that they had developed distressing symptoms of lung fibrosis after discontinuing mining and living 4 to 8 years under good hygienic conditions. During their years of exposure they experienced only slight symptoms bearing upon the condition of their lungs. Dyspnea was a characteristic symptom, and a few complained of pleural pain; most of the men, however, appeared in excellent health although exhibiting limited chest expansion. The lungs of one of the men who died with chest symptoms about 8 years after leaving the mines showed fibrosis, with scarcely any alveoli remaining. According to the authors, the ore of these mines averaged about 35 percent silica.

According to McCord (330), incipient cases of silicosis will continue to develop after exclusion from the industry, but in some instances they live a long life. With regard to treatment he stated that there is no other than the symptomatic treatment required by the cardiac impairment, tuberculosis, and bronchitis that are likely to ensue, but there is no specific treatment or prospect of betterment in well-established cases.

"Protective" Dusts as Preventive or Curative Agents

For several years many investigators have considered certain dusts--coal, hematite, shale, limestone, cement, and clay--not only as harmless in themselves but as exercising a favorable effect when inhaled with more dangerous dusts. A few, however, have claimed that although some dusts are more dangerous to health than others all dusts are more or less harmful if inhaled in large enough quantities over long periods. The comparatively recent development of better methods of diagnosis and more thorough investigation of the physical condition of workers in dusty industries are gradually leading to a realization of the fallacy of using so-called "protective" dusts to prevent or cure diseases caused by the so-called "dangerous" dusts.

It was believed that "protective" dusts would cause the excretion from the lungs of such harmful dusts as silica by exciting a physiological process of elimination and that they acted in some way to prevent the development of tuberculosis. The idea evidently was based on the assumption that miners exposed to coal and certain other "inert" dusts were free from silicosis. Since about 1914 there has been considerable discussion and argument on this subject in the technical and medical press; a brief review of some of the arguments for and against the value of certain dusts as protective or curative agents follows:

Coal dust.- From the results of experiments made at the suggestion of Haldane with a view to classifying dusts as those that predispose to phthisis or other serious lung diseases and those that do not Mavrogordato (331) drew the following conclusions:

> The initial reaction is greater to "inert" dusts than to "dangerous" dusts, and their elimination is more rapid and more complete. The admixture of inert dusts such as coal and shale with dangerous dusts stimulates the initial reaction and brings about the elimination of more of the dangerous

dust than would be eliminated in their absence. With the dangerous dusts, the rate of elimination being slow, the dosage must be very small to avoid accumulation. The more free crystalline silica is from certain inert dusts, the less is the elimination and, therefore, the greater the accumulation in the lung tissues and the greater the fibrosis resulting.

In a discussion of the question as to whether the introduction of rock dust into coal mines to prevent explosions would offer a health hazard to the miners, Oliver (332) in 1920 stated:

> A coal miner's lung, if it is free from recurrent bronchial catarrh and is not too strongly impregnated with dust, can be fairly rapidly cleared of dust, whereas in the case of the gold miner and the Sheffield steel grinder and workers in some other dusty trades the particles of inorganic material remain in the lung.
>
> Since it appears, therefore, that the lung behaves differently toward different kinds of dust, we naturally ask ourselves why this should be so. Why do coal and shale particles disappear from the lungs of miners, while those of flint and quartzite are not removed, for in shale dust there is present a small quantity of quartz and the particles of dust are just as hard and angular as those obtained from the rock of South African gold mines? So far as injury inflicted upon the lung is concerned, it does not appear that the injury is caused by the crude chemical composition of the dust. It depends in all probability upon the power which certain kinds of dust possess of absorbing other substances. In my address to the Congress of Hygiene and Demography in Washington, U.S.A., in 1912 I showed, as the result of experiments carried on over a period of many months, that coal dust and pieces of coal varied in weight from day to day and that this was due to the power coal possessed of absorbing gas from the atmosphere: In a word, coal absorbs and evolves gas just as in ordinary respiration. It was quite different in my experiments with stone dust; with this there were no such interesting rises and falls of weight as with coal dust. Haldane has gone further and has suggested that insoluble dust particles are attractive and stimulating to the large pulmonary phagocytic cells in proportion to the soluble substances which the dust particles have themselves absorbed; that dust particles which have not absorbed such soluble substances or have done so only to a limited extent will be correspondingly unstimulating. Mavrogordato continued the experiments on Haldane's lines and allowed animals to breathe an atmosphere containing in suspension both coal and flint dust, with the result that when in due course he examined the lungs of animals which had inhaled the combined dust, the whole of the flint particles had practically been removed.
>
> It appears, therefore, that since experience and experiment alike show that the inhalation of coal and shale dust when breathed in moderate quantities is not followed by permanent injury to the lungs, since this kind of dust stimulates phagocytic activity, and since it appears that flint and quartzite particles which have reached the lung are also removed, there can be, therefore, little pulmonary risk incurred by coal miners when, in order to prevent explosions in the mines, stone dust is sprayed upon the fine carbonaceous dust which is so frequently present in certain mines.

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In 1922 Collis (333) called attention to the lower incidence of phthisis claimed for coal miners compared to that for other workers. He quoted experiments of Wainwright and Nichols in which they exposed guinea pigs for about 2 months to coal dust and then injected a culture of tubercle bacilli. These animals were said to have developed "extensive tuberculosis of the abdominal viscera and of the glands around the tracheal injection, but the lungs were free"; control animals were said to have developed "extensive tuberculosis of the lungs and abdominal viscera." Such facts, according to Collis (333), have been cited to support the claim that coal dust in some way protects against tuberculosis. He stated, however, that should coal dust possess the power claimed for it workers at the coal face might be expected to experience a lower mortality from tuberculosis than other workers underground and others underground a lower mortality than those employed aboveground. The mortality data which he collected did not justify this anticipation but showed that throughout life the mortality from tuberculosis of men working at the coal face was higher than that for others below ground and, except for ages 20 to 34, inclusive, was higher than for those working aboveground; surface workers, on the other hand, up to 55 suffered more than others below ground. Collis concluded that "these data do not support the supposition that coal dust protects the workers against phthisis."

Two facts stand out rather clearly in the discussions regarding the comparative harmfulness of silica and other dusts. One is that silica is more dangerous because it apparently predisposes to tuberculosis more than other dusts. Irvine, Simson, and Strachan (129) state that "it is common knowledge that a lung affected by silicosis is peculiarly prone to become infected with tuberculosis." The second fact is that the mortality rate is highest in later years. According to Collis (334), the mortality rate for phthisis in the silica group always exhibits its highest incidence later in life--between 55 and 64--than does that for ordinary pulmonary tuberculosis. He states:

> This characteristic, which has been established from mortality records of definite silica groups, is important, quite apart from any light it may shed on the way in which silica acts. Thus, coal miners have always had a low death rate from phthisis, but this low death rate, since 1890 when statistical records first became available, has consistently shown a maximum incidence late in life, between the ages 55 and 64, at the very period picked out by silicosis.

The investigation at Picher (89) revealed that an average of 11.9 years was worked before first-stage silicosis developed and an average of 19.4 years before first-stage silicosis plus tuberculosis developed; second-stage silicosis plus tuberculosis developed in 18 years, and third-stage silicosis plus tuberculosis developed in 11.5 years (only 2 cases).

The United States Public Health Service in a recent investigation (335) found the prevalence of pulmonary tuberculosis among hard-coal miners below 35 years to be only slightly less than among male adults in the general population, but in the age groups above 35 the prevalence among the miners ranged from 2 to 10 times the rate among the males in the general population. These figures seem to emphasize the fallacy of concluding that because the incidence of tuberculosis among coal miners is somewhat less in the early years (probably owing to selection of the physically fit for mining work) than in the general population that coal miners do not have the disease. In a few years after the dust has had time to affect the respiratory passages the incidence of tuberculosis apparently increases rapidly.

Haldane (336) believed that the coal miner was free from silicosis because the inert silica dust was carried away by phagocytes stimulated by the coal, but Kettle (10) disagreed with this theory, as indicated by the following statement:

> Coal dust itself is a complex substance and varies in composition, but all coals consist largely of carbon; is carbon therefore antagonistic to the tubercle bacillus? Carleton suggests that "it is conceivable that pulmonary tuberculosis might favorably respond to a carefully graded inhalation of coal or soot particles", but I should imagine that the failure of this form of therapy is being demonstrated daily among the consumptives of our great cities. I know of no experimental evidence to support this view, and moreover I have not been able to demonstrate any difference from the normal, in their reaction to the tubercle bacillus, of animals saturated with carbon in attempts to block the reticuloendothelial system.
>
> The demonstration of silicosis among coal miners is of such importance because a whole superstructure of theory has been built upon the assumption that it does not exist. From observations in man and in experimental animals we know that when coal is inhaled into the lung it is picked up by phagocytes. By the migration of these phagocytes much of the dust is removed, either by way of the air passages or by the lymphatics. If the quantity of dust inhaled is great, intake will overcome excretion and the coal will remain in the lung. Much of it is deposited in lymphatic vessels, but from the fact that a miner's sputum is pigmented for a long time after he ceases work it would seem that a good deal still remains in the alveoli. The pigmented lung of the city dweller suggests that the excretion is never perfect, but yet it has been claimed that small quantities of coal may entirely disappear from the lungs of experimental animals by this natural method of cleansing. ***.
>
> I have confined my remarks to coal dust because this is the adulterant dust most often quoted, but I have no reason to believe that other concomitant dusts in industries play any specific part in protecting the individual from the effects of inhaled silica. The experiments which have been accepted in the past as having significance are not capable of giving the answer required. We must have a base-line to work on, and in these experiments the base-line must be the production of characteristic silicosis in animals. In the absence of this we are not justified in claiming experimental knowledge of how silicosis may be modified.

The following statement by Böhme (337) regarding pneumoconiosis and tuberculosis among Ruhr coal miners indicates that these diseases do occur among coal miners:

An examination of hospital cases revealed that of 103 coal miners that had been in the work for 10 years or more 30 percent showed pneumoconiosis roentgenologically, while of 66 stonemasons 70 percent revealed pneumoconiosis, mostly of a severe type. Among stonemasons with pneumoconiosis there was found in most cases a high-grade secondary tuberculosis. Among 95 coal miners in this occupation over 10 years there were 5.3 percent with open tuberculosis, and 2 other cases revealed, clinically and roentgenologically, a fibrotic closed tuberculosis. In all there were 18 percent which had then or previously suffered tertiary pulmonary tuberculosis. Among the stonemasons 12 percent were open, 8 percent definitely active, and 23 percent were or had been in the tertiary class.

Carleton (338) experimented with dusts composed of flint and coal, china clay, feldspar, ground pitcher (earthenware), pure amorphous silica, pure flint, coal, shale, ignited shale, dried earth, and ignited earth. Coal was found to initiate early phagocytic response which led to rapid elimination of much, but not all, of the flint dust simultaneously inhaled. He suggested that possibly coal dust might be beneficial in metalliferous mines. China clay, contrary to expectation, was found a potentially dangerous dust, as also were feldspar and ground earthenware. Inhalation of amorphous silica produced lesions even more severe than inhalation of crystalline silica. Coal dust was eliminated rapidly from the alveoli owing to brisk phagocytic response. Shale dust was comparatively harmless, even when previously ignited. According to Carleton (338), "when the paths of dust elimination are examined the more harmful a dust is to the lungs the less far is it found to be removed from the alveoli and the less complete is its removal."

The incidence of silicosis among coal miners in South Wales employed in driving roads in hard silica rock was reported in 1926. Cummins (339) gives an account of the pathological findings in one of these miners who, after exposure to silica dust for 4 years at machine drills, was employed as a coal miner at the face. Neither during life nor after death were tubercle bacilli found. On chemical analysis the lungs were found to contain a little over 10 percent ash, of which 1.4 percent was silica. Ash from the lungs of an ordinary adult gave only 3.2 percent ash with an inconsiderable amount of silica. Microscopically, the lungs exhibited definite and characteristic fibrosis; in addition, a large accumulation of pigment originating in coal dust was found--so much that the upper parts and surface of the lungs felt and looked like coal. Many dust-bearing macrophage cells were seen in the fibrotic tissue, carrying particles of coal dust. Others had disintegrated, leaving their burden of coal dust behind. Cummins (339) compared the occupational exposure of the patient to that of guinea pigs exposed by Mavrogordato first to fine silica dust and later to fine coal dust. The findings agreed closely with those reported by Cummins. The suggestion is made that the lungs were first damaged in their lymph drainage by the fibrosis and subsequently coal dust became entangled there which would have been eliminated from normal healthy lungs. The result was that coal dust, usually considered a harmless dust, accumulated in the lungs and accentuated the preexisting silicosis enough to cause death.

According to Collis (340), coal trimmers (men working for long periods in semiclosed spaces in the holds of ships) exposed to dust from South Wales coal tend to succumb in excess from bronchitis and pneumonia, but not from phthisis. Clinical observation by X-ray examination disclosed that after years of work the lungs of coal trimmers are not normal and exhibit signs similar to those widely regarded as characteristic of silicotic fibrosis.

That dusts other than silica do not prevent silicosis and tuberculosis when inhaled with silica is indicated by Hague and McBain's (341) summary of results of an examination of 4,000 miners of the Porcupine group of mines in Ontario, Canada. They state:

1. The local incidence of silicosis is low in comparison with the Rand of South Africa.

2. The pulmonary condition, as roentgenographed, presents here a picture with contrastingly softer shadows than those from South Africa.

3. "The condition is of much less erious nature and would seem to be caused by rock dust (a) other than silica, (b) containing a small percentage of siliceous dust mixed with that from silicates and other accessory minerals" (C.M. Omerod).

4. Tuberculosis is the predominating serious factor but does not exist to nearly the same extent or virulence as that of South Africa.

A summary in the Colliery Guardian in 1931 of results of investigations by Cummins (342) contains some interesting statements on the value of coal dust in the prevention of silicosis and the treatment of tuberculosis.

A point which comes out clearly from these investigations is that the anthracosis of coal miners is a dual condition in which the retention of coal dust in the lungs is associated with and, in all probability, due to, a state of diffuse or nodular lung fibrosis and lymph blockage indistinguishable from that found in the silicosis of gold miners on the Rand and of those engaged in the "refractories" industries in this and other countries. In the coal miners' lungs the extent of the fibrosis and lymph blockage, the percentage of silica in the lung ash, the number of doubly refractile particles visible in the sections, and the degree of clinical pulmonary disease recorded prior to death are all found to vary directly with the amount of exposure of the individual to silica-containing dust, being greatest in those with an industrial history of work in "hard headings" or as "repairers", although often quite marked in coal miners with no history of work other than at the coal face. The author declares that, in a large proportion of old coal miners of other categories less intimately in contact with stone dust, there is radiological, pathological, and chemical evidence of a condition indistinguishable from pulmonary silicosis. One characteristic feature of silicosis, however, is absent in the case of coal miners--the increased liability to tuberculosis. In fact, there is much reason to think that coal miners, far from being specially liable are, on the contrary, exceptionally resistant to pulmonary phthisis. The writer's observations into the anthracosis of coal miners suffice to convince him that the simultaneous inhalation of silica dust and coal dust over long periods leads to a blocking up of lymph drainage by silicosis and a resulting retention of the coal dust in the lungs rather than to any increased elimination of one dust with or through the other.

The writer has been able to prove beyond any question that the finely powdered dust of anthracite coal is capable of adsorbing a large proportion of the active principle from old tuberculin diluted with normal saline solution. It is not unreasonable to assume that the presence of large quantities of carbon particles in the immediate vicinity of tuberculous foci might, by adsorbing the products of the growth and destruction of tubercle bacilli, go far to prevent or diminish the inflammatory phenomena which constitute tuberculous disease. Whether the collection of carbon particles which have accumulated in the tissues and been bathed in the tissue juices retain their power of adsorbing tubercle protein is a matter for further investigation, but the probability that they can do so is emphasized by the fact that negative sputa are commoner in clinically tuberculous coal miners than in clinically tuberculous adult males of other occupations in the same district and over the same period. If the relative exemption of coal miners from tuberculosis be admitted, and it can hardly be denied, then this fact must be taken into consideration along with the further fact, newly established, that a large number of coal miners develop pulmonary silicosis in the course of years spent in the industry. It would be rash to suggest that this condition of silicosis in coal miners is free from risk. What tuberculosis is to the gold miner, "bronchitis", perhaps, is to the coal miner, and the high mortality from this latter cause in old colliers is in all probability closely associated with a life of exposure not only to coal dust but to stone dust as well. But the word "silicosis" has come to imply a marked and formidable liability to tuberculosis and is thus accepted in regard to "compensation" in "refractories" industries in the gold-mining industry in South Africa. It is important to dissociate this implication from the word "silicosis" when it is applied to coal miners.

In a later article Cummins (343) asks why silicosis, which is so often the herald of phthisis in the gold miner, does not have the same sinister association in the collier:

> Is it a question of some antiseptic action of the coal dust exercised in the lung tissues?

Wainwright and Nichols (1905) were unable to demonstrate any such antiseptic action, although their experiences led them to postulate a "real protective influence" of coal dust in the lungs against tuberculosis. Corper, Starry, and Lurie (1924) failed to discover any antiseptic action of coal dust in the inhibition of the growth of tubercle bacilli in culture but, like the former authors, they, too, found that the presence of coal dust in the lungs of their experimental animals had a definite protective effect against tuberculosis.

It is evident that coal dust has this protective power to a considerable degree and that it does not depend upon any antiseptic action.

The writer has recently (1931) suggested that its antituberculous properties may depend upon its well-known power as an adsorptive agent.

Tubercle bacilli act upon the tissues through the toxic products set free in their growth and disintegration. These toxic products cannot be appreciably different from those of tuberculin. ***.

It must not be supposed, however, that the presence of accumulated coal dust in the lungs is an unmixed blessing. On the contrary it may have very disagreeable or even dangerous results. While it seems to have a definitely beneficial effect in lessening the liability to the extension of tuberculous lesions it may, by its mere accumulation, come to occupy large areas of lung tissue to an extent which leads not only to fibrosis and devascularization, but sometimes to colliquative changes and even cavity formation. With these changes there is brought about, to a gradually increasing extent, a state of lung emphysema accompanied by structural deterioration of alveolar tissue, bronchioles, and even bronchi which involves serious interference with the function of respiration.

Most old coal miners are dyspneic. Although many of them work on to a great age, they are, as a rule, "short of breath" and suffer from copious sputum, cough, and sometimes asthmatic trouble.

While the collier is fortunate in having a relatively low death rate from tuberculosis, his death rate from "bronchitis" is very high. Whether the word "bronchitis" is well chosen to describe the dyspneic state in which old coal miners so commonly die is open to question; and it is a question, too, whether they merely die dyspneic or die from dyspnea. Certain it is that the effects of stone dust and coal dust combined tend, after a life spent in the industry, to produce a stage in which the breathing efficiency of the lungs is seriously compromised. ***.

The fact that the apex of the curve of "bronchitis" mortality in coal miners occurs so late in life shows that the state of lung injury does, however, involve marked respiratory distress and considerable loss of health. This pneumonoconiosis of coal miners is at least a contributory cause in many of the deaths attributed to "bronchitis" and it appears, in itself, to lead to fatal issue in some cases. The attitude of complacency commonly assumed toward the risks run by coal miners from exposure to the mixed dusts of the coal mines is obviously unjustifiable.

(344) Coal dust has been used in the treatment of pulmonary tuberculosis. Glaser administered intravenously 3 cc of a coal-dust preparation, repeating the injection after an interval of 10 days; only 3 injections were given. After each injection the patient was kept in bed for 3 days and the temperature taken every 2 hours. The injections caused pleuritic irritation in one patient and bloody expectoration in another. In one instance the treatment was followed by rapid subsidence of fever; usually the subfebrile temperature persisted

or even developed afterward. The sedimentation speed of the erythrocytes sometimes was reduced or remained unchanged; the general condition improved. The injections proved most efficient in patients with catarrhal lesions, but the effect was transitory. Remarkable improvement was observed in a case of ulcerous productiveocirrhotic tuberculosis after two injections. Glaser points out that the reaction caused by the intravenous injections was different from that caused by inhalation of carbon dust by miners.

Böhme (15) arranged dusts according to harmfulness in the following descending order: Steel-grinding dust, coarse pottery dust, fine pottery dust, coal dust, and soot. He considers the last two probably less harmful than grindstone and pottery dust but states that animals exposed thereto when compared with controls undoubtedly showed that coal dust and soot favored tuberculosis--"an observation of importance in the face of many statements to the contrary, which are mostly based on insufficient material."

In 1934 Fowweather (345) stated that, in general, the dusts in some industries are more potent as silicosis producers than those of other industries; the nature of the inhaled silica has something to do with the onset and development of the disease; possibly, too, accompanying nonsiliceous dusts may exert a modifying effect on the action of the siliceous material inhaled. In his opinion some modifying effect of coal dust, for example, may account for the difference observed between the silicosis of coal miners and that of workers in industries in which coal dust is absent.

Cooke (346) summarizes briefly the trend of thought regarding coal dust:

> A century ago the dangers of inhaling coal dust were accepted; at a later period, associated with a discovered low tuberculosis rate, they were discountenanced; today the dyspneic coal miner with his constant cough, associated chronic bronchitis and emphysema, black lung, resistant and airless parts, with or without pleural effusion or abscesses, and with an abnormally high silica content, is again becoming of serious concern. Although it is probable that the work of Cummins and Weatherall explains the immunity to tuberculosis on the basis that coal dust absorbs the active principle of tuberculin, the other gross pathology--bronchitis, emphysema, and fibrosis--must not be forgotten.
>
> Oliver (1909), Collis (1915), Tattersall (1926), and others have also proved beyond reasonable doubt that there is a serious impairment of lymph drainage in the lungs of coal miners by the action of silica.

Cooke (346) describes a case history, with autopsy, of typical "silico-anthracosis" in a soft-coal miner who had no other employment throughout a long life and whose lungs showed extensive fibrosis, occasional fibrous whorls, emphysema, carbonaceous deposits, and masses of golden-yellow pigment, as well as black angular particles measuring 10 to 80 microns in length. In many respects the curious bodies were those considered typical of asbestosis only, although the miner in question had not been exposed to strata containing iron ore or large amounts of silica. Cooke therefore questioned the constancy of the peculiar bodies in asbestosis. He considers that this case lends strong support to the theory that anthracosis is primarily a silicosis and that it occurs not only in hard-coal miners but also in workers in soft coals.

Calcium dust.- Authorities have considered calcium dusts the least harmful of the inorganic mineral dusts; in fact, some believe that certain calcium dusts play an important role in hindering the development of tuberculosis or in arresting its progress, basing their view on the physical and chemical qualities of the dusts, on clinical reports, statistical data, and brief animal experimentation. The following review of the literature on this subject is taken from an article by Iszard (347) on Calcium and Tuberculosis, published in 1925.

In discussing the question of mineral dusts in the lime and cement industries Hoffman (348) showed by citing investigations, quoting authorities, and comparing statistical data that "mineral dusts composed of calcium salts are the least injurious of inorganic mineral dusts." In a review of Hoffman's paper the Monthly Labor Review (349) stated that "the evidence is also conclusive that workers exposed to marble or limestone dust suffer a decidedly lesser liability to pulmonary tuberculosis than those exposed to granite or sandstone dust with a high silica content."

According to Koelsch (350), Summerfield claimed that of 20 workers occupied up to 30 years in a Berlin gypsum factory none showed signs of tuberculosis.

Rössle (351) claimed that mortality from tuberculosis among workers in lime and cement industries was favorable, and when tuberculosis is found among these workers it always develops slowly.

According to Nieszytka (352), Hirt claimed that chalk, gypsum, and cement were the least harmful dusts for the respiratory organs. To show the value of calcium therapy in pulmonary tuberculosis, Maendl (353) quoted Fissak, who stated that of 40,824 deaths only 17 (0.041 percent) occurred among calcium and gypsum burners; the German gypsum union claimed that of 400 workers employed for 17 years in a gypsum factory not one had died of tuberculosis. For this reason Maendl thought that methodical gypsum-dust inhalation treatments should be given tuberculous patients.

Reckzeh (354) cited the case of a worker suffering from pulmonary tuberculosis who, on changing his employment to lime-burning, found after several months that his condition had improved. Investigations of several lime factories resulted in negative tuberculosis reports. According to this investigation (354), Halter attributed the beneficial action of calcium to its dehydrating action on air and Weber, Hirsch, and Hunter claimed that the dryness of air containing calcium has a drying action on the pus. Reckzeh (354) treated 8 tuberculous patients with lime; he placed them in a room for 5 minutes a day and created dust by beating bags containing lime. No positive results were obtained.

According to Nicholson (355), all dusts are not equally harmful; coal possibly is beneficial, lime neutral, and silica injurious. Thompson (356) stated that "upon the whole, in proportion to the quantity of dust inhaled, cement dust, like coal dust, produces less damage to the respiratory system than might be supposed--less than the harder, sharper flint or glass dust, although chronic bronchitis, asthma, and pneumonoconiosis may result from it."

As a result of personal investigations among limeworkers, Selkirk (357) concluded that they showed exceptional health and cited Renon as saying that when a limestoneworks opened up in a particular place there was a decrease in tuberculosis among the people of the neighborhood. Selkirk (357) suggested that individuals predisposed to tuberculosis should work in cement and lime and that perhaps a limeworks should be started as a tuberculosis cure.

As a result of investigation of the dust problem in some portland-cement plants, Tucker (358) claimed that there was "no evidence of injurious effects from cement dust on employees engaged in its manufacture." This conclusion was based on the examination of 956 employees of 1 plant and of the men employed in the dusty departments of 4 other mills, as well as on hospital records and guinea-pig experimentation.

In an article on lime and tuberculosis Rockwood (359) likewise suggests the possibility of lime dusts having a beneficial effect on pulmonary tuberculosis and causing an inhibition of the tuberculous process. He based this belief on an intensive and interesting series of reports from managers of plants engaged in the manufacture of calcium products.

Tweddell (360) visited 22 plants and found no cases of tuberculosis; a number of gypsum manufacturers (361) make similar reports.

Nagai (362) made experiments with guinea pigs, exposing one series to lime dust alone and another series to lime dust containing tubercle bacilli. These dusts were kept in suspension by mechanical agitation. The results showed that lime dust alone had no detrimental effect. When lime dust was superimposed upon a tuberculous involvement or when the dust and bacilli were administered simultaneously the dust had no demonstrable beneficial action.

Cesa-Bianchi (363) conducted a series of experiments in which he dusted guinea pigs with chalk, coal, Thomas slag, gypsum, cement, and mother-of-pearl to study the effect on their lungs. He dusted other animals with the same dusts and superimposed a human strain of the tubercle bacillus; the amount used produced little or no alteration in normal animals. The dusts alone caused no marked alterations of the air passages, particularly no alteration of the lining parenchyma. When the tubercle bacillus was superimposed a marked mediastinal involvement and great swellings of the peribronchial lymph nodes were observed. The author said that all dusts produced similar results except chalk and gypsum, leaving the reader in doubt as to whether he considered these beneficial.

Gardner and Dworski (364) found that the greater portion of inhaled marble dust is soluble in the lung tissues and that the inhalation of this dust during the progress of a preexisting tuberculosis will be followed by the calcification of a certain number of the pulmonary and tracheobronchial lymph-node tubercles. The insoluble siliceous matter causes a small amount of silicosis after prolonged exposure and delays the resolution process.

Iszard (347) summarizes the literature on calcium in the treatment of tuberculosis as follows:

> The statistical data of the United States show that tuberculosis mortality is higher for all calcium-dust industries than for the population as a whole. The percentage, however, is markedly lower than for those industries involving exposure to dust of high silica content. Furthermore, exposure to calcium dust appears to retard the development of the tuberculous process since in the calcium industries the tuberculosis mortality peaks are reached much later in the age scale than in the other dusty trades.
>
> Foreign statistical data rather give one the impression that the calcium industries are beneficial, especially the lime and chalk industries.
>
> Clinical and industrial reports point to either a harmless or a beneficial action of the calcium dusts. The reports from those who have employed calcium dusts in the treatment of tuberculosis vary as to their value. Those employing calcium oxide, with the exception of the French workers, claim that it is of no benefit, while those using calcium sulphate feel that it is helpful in the early stages. The ineffectiveness of the former can be attributed to the caustic action of this dust.
>
> Animal experiments point rather to the fact that calcium dusts act as mild irritants and though playing no important role in the development of tuberculosis, do not arrest its development.

From original experiments, Iszard concluded:

> Calcium hydrate dust is not harmful to the lungs of rabbits. It apparently acts as a mild stimulant, causing the migration of macrophages which remove traces of silica present in the calcium dust. The harmlessness of calcium hydrate dust may be attributed both to its physical and to its chemical nature. The roundness of its particles prevents them from doing marked injury, and their tendency to coalesce prevents many from gaining access to the finer bronchioles. Moreover, the fact that it is soluble in the body fluids permits of its partial removal by way of the blood stream.
>
> When inoculation with tubercle bacilli follows a period of lime-dust inhalation there seems to be a very slight retardation in the development of tuberculous lesions, which nevertheless are indistinguishable from the customary lesions of this infection in rabbits.
>
> When the lime-dusting occurs after the inoculation with tubercle bacilli there is a more distinct retardation of the tuberculous development explainable possibly on the ground that the lime causes an overproduction of macrophages which render inert the tubercle bacilli. Since the lime is soluble in the body fluids there is no noticeable accumulation of foreign mineral matter.

> As dissolved calcium is in the blood stream always as bicarbonate and phosphate, the excess, introduced by such experiments as have been detailed, must be deposited in those organs normally characterized by a high calcium content, such as the bones, kidneys, and lungs. In a tuberculous condition, where we have a calcium demineralization, any increase in calcium would tend to balance the existing deficiency and permit of an approach to normal.

Koelsch and Kaestle (365) found that the mortality rate for cementfactory workers did not differ from that for the local population of the same ages but rather remained considerably under the average for the district; the tuberculosis mortality rate in particular was within 10 years under the average for the whole Bavarian population.

In six autopsies of workers in the cement industry Pesenti (77) found sclerosis localized at a few points in the lungs. He believes that the nodular, bronchopulmonary sclerosis follows a slow evolution and provides few subjective symptoms. He noted dyspnea, loss of weight, night sweats, pleximetric and stethoscopic phenomena, and sputum similar to that of tuberculosis in a person in whom tuberculosis was not discovered either macroscopically or microscopically at autopsy; it was a case of multiple nodular sclerosis of the lungs. Pesenti (77) believes that inhaled cement dust neither produces tuberculosis nor favors its evolution but states that this is merely a hypothesis, Loriga (77) considers these observations highly interesting because they present a picture of the various forms of pneumoconiosis without tuberculosis

From a clinical and statistical study Rota and Finzi (77) found that workers in cement and lime have no higher morbidity and mortality rates than other workers, although they are subject more frequently to respiratory diseases and often die at an early age. They state that there is no truth in the belief that limekiln workers enjoy a certain immunity from tuberculosis.

According to Russell (366), cement workers of a group that showed positive signs of arrested tuberculosis were able to work in the dusty atmosphere without any apparent harm to their old tuberculous lesions. He states:

> The amount of calcium in relation to silica or other constituents of inhaled dust appears to be of importance in the incidence and development of industrial tuberculosis. Two facts in this connection stand out prominently in the study: First, no new cases of tuberculosis were found to have appeared as the result of exposure to cement dust; and, second, the cases which had unmistakable evidence of arrested tuberculosis exhibited no tendency to reactivation of the disease. We are led to believe that exposure to dust generated in the manufacture of portland cement is not provocative of tuberculosis, nor is it a factor in reactivation of arrested disease.

Chemical analysis showed that the cement contained about 62 percent of lime and 22 percent of silica. Petrographic analysis showed that the proportion of free silica (quartz) ranged from 6.5 percent in the crusher houses, raw mill, and stone house to about 1 percent in the finished cement. In contrast to the effects mentioned in connection with tuberculosis the frequency of disability on account of respiratory diseases among cement workers was twice as great as the average respiratory rate among employees of 11 manufacturing plants in relatively nondusty industries. The highest rate for all respiratory disease in any of these establishments was 30 percent below the rate of cement workers.

During 1934 and 1935 much attention has been directed to suits filed in the courts of various parts of the United States, alleging harm to health from breathing dusts; in several hundred of these the complainants have alleged that they have been wholly or partly incapacitated by breathing dust composed chiefly of limestone. Several rather heavy judgments have been awarded in these suits (which generally, however, were appealed), some of them in connection with breathing dust containing less than 3 percent (and in some cases less then 1 percent) silica; the main constituent was limestone.

Confidential data in the possession of the authors indicate that some coal-mining companies using pulverized limestone dust for rock-dusting to prevent coal-dust explosions have had difficulty with employees engaged in the rock-dusting work who have complained that the breathing of the accompanying large amount of the fine rock dust (90 percent or more limestone and usually less than 5 percent silica) has caused serious illness; in some cases the employee has been taken off the work and in other cases he has been provided with an up-to-date dust respirator.

Clay dust.- In 1919 Landis (367) stated that he knew of several potters who became tuberculous, had the disease arrested, and returned to their former work. In each case after a number of years had elapsed the patient was well in spite of being exposed to the same conditions as existed before his illness.

As mentioned above with regard to coal dust, apparently the fact that workers in certain dusty industries do not succumb to tuberculosis at as early an age as the tuberculous victims who have not been exposed to industrial dust is the basis for the belief that certain dusts exert a "protective" action against the development of the disease. However, the force of this argument for the "protective" value of such dusts seems to be nullified by mortality figures for older workers quoted by its adherents. This point is well-illustrated by the following quotation from a report by Landis (367) on clay dust:

> It has long been recognized that the age period at which potters succumb to tuberculosis is far beyond the average, and in addition the disease seems to be much less severe than the same amount of damage produced in other classes of patients. Most of the available statistics on the subject support this view. Thus the English mortality statistics for the 3 years ending 1902 state that the mortality of potters, between the ages of 20 and 35 years, falls below that of occupied and retired males generally. At every other period, however, it shows an excess which amounts to no less than 74 percent at ages 45 to 55 years and to 66 percent at ages 55 to 65 years. The principal excess falls under the head of respiratory diseases.

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The following table shows the proportionate mortality from consumption among potters, compared with that of males in the registration area in the United States.

Age at death	Percent of deaths due to tuberculosis among--	
	Potters	Males in registration area, 1900-1906
15 to 24 years	23.9	27.8
25 to 34 years	52.9	31.3
35 to 44 years	44.0	23.6
45 to 54 years	28.2	15.0
55 to 64 years	19.4	8.1
65 years or over	19.4	2.7

My own belief is that the higher incidence of tuberculosis among those exposed to inorganic dust is due to the fact that the dust acts as a convenient carrier of tubercle bacilli. In other words, it is not the preliminary injury which the dust is responsible for that predisposes the individual to tuberculosis, but the readiness with which tubercle bacilli may be carried into the respiratory tract by a dust-laden atmosphere.

In 1925 Landis (368) stated in regard to potters that "the damaging effects of the inorganic dust become more and more noticeable after the age 40. There are relatively few workers remaining at the trade beyond the age of 60. They become incapacitated as a result either of pneumoconiosis or of a superimposed tuberculous infection."

In 1926 Heffernan (369) called attention to the relative immunity of Derbyshire silica brickmakers from silicosis, which he said was due not to the shape of the silica particles but to the fact that the material used was not pure silica but a mixture of about 84 percent silica and about 16 percent clay and earth with some organic matter; the presence of these latter materials appeared in some way to inhibit the action of the silica dust. In support of this contention he quoted the following conclusion reached by Smith and Collis (370):

> This inquiry has revealed an unsuspected fact, viz--that the influence of silica dust in favoring tuberculous infection is modified when the silica is mixed with certain clays. Ganister or other stones containing a high percentage of free silica are mixed with clay sufficient for binding purposes in the manufacture of certain refractory bricks and other articles; and stone is added in varying proportions to fire clay to increase its refractory properties or to modify or reduce the amount of shrinkage when subjected to high temperatures. During this inquiry no history has been obtained, up to the present, either from workers or occupiers that a high mortality from phthisis is experienced by those employed in the manufacture of such articles containing clay as an admixture.

Heffernan (369) states that exactly how this protection comes about "is an unsolved but very interesting problem, the solution of which may completely alter our present ideas regarding the prevention of silicosis."

The Report of the Safety in Mines Research Board of Great Britain (371) contained the following very striking deductions from the work done at the physiological laboratory of St. Bartholomew's Hospital under the direction of Haldane:

> While many dusts cause pulmonary fibrosis, silica is the dust which most predisposes to tuberculosis. This is doubtless due to its influence in forming a medium suitable not only for the survival, but for the proliferation of the tubercle bacillus in the lung (Kettle). The harmful effect of soluble silica may be neutralized by simultaneous administration of basic dusts, such as aluminium hydroxide or magnesium carbonate, though the latter are themselves harmful when inhaled alone. It is suggested that their respective solutes combine to form silicate. Monosilicates do not appear to have any harmful effect on the lung.
>
> Heavy inhalations of any dust are liable to cause pulmonary damage. The intensity of the initial pulmonary reaction to a dust is very generally in inverse ratio to the degree of eventual damage caused by the dust.
>
> The following dusts produce a fibrosis in the guinea-pig's lung and are, therefore, to be classed as dusts whose inhalation in industry would be attended by risks of pneumoconiosis. The most deadly of all dusts examined was precipitated silica. Less dangerous, but all producing fibrosis, were the following arranged in order of decreasing toxicity: Flint, slate, aluminum hydroxide, precipitated chalk, magnesium carbonate, and carborundum. In the concentrations used in the experiments calspar and emery were borderline dusts, indicating that their inhalations in any considerable quantity would cause fibrosis. Wood charcoal inhaled in large amount produces a slight fibrosis, and must therefore be considered potentially dangerous, as also must very fine coal dust when inhaled in very large amounts.
>
> Hematite, however, initiated a brisk proliferation of the alveolar epithelium on its entry into the lung.
>
> The experiments have shown that pulmonary fibrosis may be caused by dusts which in human experience are innocent in that they do not appear to predispose to tuberculosis.

The following reports of investigations on the effects of inhaling a dust containing aluminum and one containing hematite are interesting in connection with the above statements regarding neutralization of harmful effect of soluble silica by certain other dusts.

In 1932 Gudjonsson (372) reported the results of an examination of 78 workers who had been employed in a plant in Denmark for over 2 years in crushing and grading a mineral composed mainly of aluminum sodium fluoride, known in Greenland as "cryolite." He stated that half the workers on X-ray examination

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showed a condition, in different stages, similar to that found in cases of silicosis when originated by silica dust. He summarizes his results as follows:

> 1. On examination of the local conditions in a factory where cryolite is crushed it was found that most of the working processes were accompanied by the production of mineral dust, cryolite, containing only 3 percent quartz and that in some parts of the plant the dust production was very marked.
>
> 2. An examination of 78 workers, who had been occupied in this place over 2 years revealed various degrees of silicosis--up to second stage--in 40.
>
> 3. The development of silicosis appears to be in direct relation to the time the workers affected have been occupied in this place, and not in direct relation to their age.
>
> 4. The total sick rate during the last years has increased among the workers with silicosis. This applies especially to diseases of the lungs--in this group of diseases the total sick rate is more than 3 times as high among silicotic workers as among nonsilicotic.
>
> 5. Signs of pulmonary tuberculosis were demonstrated in four of the workers examined, but they were not confined to silicotic workers.

In 1926 Cronin (371) reported on an examination of 100 drillers in iron mines; the main geologic formation met by the drillers was hematite and limestone. The medical history of these drillers was particularly clear; some had been drilling for 30 years without a day's absence from illness. Among the 100 subjects the only illnesses contracted during the period spent in drilling were a few cases of mild influenza, a case each of lumbago, neuritis rheumatism, and 2 cases of pleurisy; 27 percent of the men made no complaint whatsoever. Nevertheless a large proportion of the men definitely admitted certain symptoms arising from inhalation of the dust. Furthermore, these symptoms were constant in different districts, a fact that eliminated the possibility of collusion among the men and strengthened the evidence considerably. Cronin (373) divides the symptoms experienced into immediate or transitory and permanent. The immediate symptoms were irritation of the nose and throat during drilling, a "clogged-up" feeling, and a tendency to hawk up the dust for a short time after coming out of the mine, but there was no permanent cough. The most constant permanent symptom was shortness of breath often admitted by young men; this was not experienced at rest but only on exertion ranging in severity from climbing a hill in severe cases to the use of a drill in mild cases. Shortness of breath on exertion was much in excess of the normal and could not be explained by symptoms of cardiac insufficiency or correlated with symptoms of other lung diseases such as asthma, bronchitis, or large-lunged emphysema. According to Cronin (373):

The physical examination of these men revealed certain striking facts, particularly outstanding when contrasted first with the physical condition of the men who had drilled in South Africa, and then with the condition of the controls, i.e., men who had been working underground in the hematite mines for many years, but who had not been exposed to the dust.

Sixty-four of the 100 drillers examined could be classed clinically as possessing normal chests or conversely as affording at least no distinct clinical evidence of pathologic change in the lungs. On the other hand, while 6 percent were doubtful, 30 percent showed very well-defined and constant features, which were, in the order of their importance:

1. Loss of ability to expand the chest fully on forced inspiration. In producing this expansion the subjects were able to use, and did use markedly, the accessory muscles of respiration.

2. An abnormal accentuation of the supraclavicular and the infraclavicular hollows, usually corresponding with a slight flattening of the chest in these regions.

3. While there was an absence of variation in the note on opposite sides, i.e., evidence of patches of massive fibrosis or of pleural involvement was constantly lacking, the note elicited on percussion was in many cases generally duller and less resonant than normal.

4. In certain cases there was found a well-marked deviation from the normal breath sounds, which assumed an almost puerile or at least bronchovesicular character. In only one case were adventitious sounds in the nature of rales and ronchi obtained, and this was in a case of chronic bronchitis contracted 10 years before the man had commenced to work underground. There was no evidence of any pleural involvement on auscultation, except in one case where over a limited area a doubtful crepitation might have existed.

Cronin (373) concluded from his investigation that--

1. The inhalation of hematite dust produces certain tissue changes in the lungs of iron-ore drillers.

2. Such changes are not localized but are generalized or diffuse throughout both lungs, although the apices are perhaps more affected than the bases.

3. These tissue changes do not give rise to the pulmonary diseases, i.e., asthma, bronchitis, pneumonia, and phthisis, which commonly result from dust inhalation, but produce the independent and striking sympton complex which has already been described.

These deductions are given additional weight by comparison with pathologic research. Clinically the results of hematite inhalation do not resemble those of silica inhalation but present a unique picture, while the sections obtained by Sir Kenneth Goadby from the lungs of an iron stone miner clearly indicated not only the presence of a considerable amount of iron as shown by differential staining but also a fibrosis which was essentially general throughout the lungs, finer and quite opposed to the nodular whorled masses of the silicotic lung.

Among the thousands of lawsuits that have been instituted in the courts of the United States in the last few years in connection with dust disease scores (possibly hundreds) of them are by workers in iron-ore mines where the main component of the material handled is hematite and the silica content is usually less than 20 percent and often less than 10 percent. Many of these cases have been diagnosed as silicosis, and in some instances tuberculosis is said to have intervened; several of these suits have been settled out of court.

Alkali Method

Another method tried in the treatment of silicosis is the use of alkalies like sodium bicarbonate. The treatment is based on the observation of the investigators that when silica in solution or as powdered quartz enters the blood stream from the digestive tract it is eliminated quickly by the kidneys; the same is true when solutions of silica are injected directly into the veins, as the body apparently has a very efficient mechanism for disposing of silica after it has entered the blood stream in soluble form. Tests on miners and on healthy laboratory workers who had been exposed to a large amount of quartz dust for a day showed that they were actually eliminating more than the normal amount of silica; evidently the mildly alkaline tissue fluid in the lungs was dissolving some of the silica inhaled and as a result it was entering the blood stream and being eliminated. In the hope of accelerating this natural effort of the body to rid the lungs of disease-producing silica King and Dolan (374) gave alkali medicine, but the results were inconclusive.

In this connection it is interesting to note the results of a study by the United States Public Health Service (375) of the urinary excretion of silica by persons exposed to silica dust. One hundred and twenty-three anthracite workers, 20 of whom had been out of the industry an average of 7 years, were examined for urinary silica by the method of King and Dolan. The amounts of silica found in the urine ranged from 0.6 to 11.7 and averaged 2.5 mg per 100 cc. Normal individuals were found to be excreting only an average of 1.0 mg per 100 cc. A close correlation was found between the silica-dust exposure of these men for a specified number of years and the amount of urinary silica. A study of former anthracite workers showed that even after a lapse of several years away from any silica-dust exposure they were excreting an increased amount of silica.

The data cited above emphasize the divergence of opinion (and even difference in experimental results) of various investigators regarding the harmfulness of certain so-called "protective" dusts and their efficacy in preventing silicosis and tuberculosis when mixed with dusts definitely agreed upon as harmful or their harmlessness when breathed alone.

Section 5. - General Recommendations for Control of Dust Diseases in Industry

Although referring to general industrial diseases, the following recommendations from a report by Bloomfield and Johnson (376) who at the request of health officials investigated conditions in an industrial area in the United States, will serve as a summary of the control of dust diseases in industrial work outlined in this chapter.

The practice of industrial hygiene (control of occupational diseases) falls largely within the province of two types of workers, the physician and the engineer. It is within the sphere of the physician to diagnose occupational diseases and primarily to recognize the existence of those diseases due to the factory environment. Based on the findings of the physician, the engineer is in a position to learn where control measures should be initiated. The engineer's work consists of studying the local plant conditions which have been shown to be detrimental to health and evaluating the various methods which may be designed for controlling the hazards. It is impossible to tell by a mere inspection of a workroom whether toxic materials are present in the air in such quantities as to constitute a hazard and whether the protection afforded is adequate. Precise quantitative measurements are needed. Once these measurements have been made, the engineer is able to determine definitely the extent of the hazard and the necessary remedial measures.

In order to carry out a constructive program of industrial hygiene the minimum requirements are:

(A) A physician thoroughly trained in public-health procedure and having a comprehensive knowledge of the effects upon health of the various materials and processes used in industry; in other words, one trained in industrial hygiene.

(B) An engineer who is also trained in industrial hygiene and who is familiar with industrial processes. He should know the following subjects from both a theoretical and practical viewpoint:

1. Microscopy.
2. Gas chemistry.
3. Mechanics of ventilation.
4. Physiology of ventilation.
5. Industrial sanitation.
6. Illumination.
7. Industrial-hygiene survey methods.

(C) A completely equipped laboratory for carrying on studies in industry. With such personnel and facilities, the following program could be inaugurated:

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1. Reporting of all occupational diseases to the division carrying on industrial-hygiene work. This will definitely establish where and to what extent certain occupational diseases are occurring and suggest corrective measures.

2. In order to acquaint industry, the medical profession, and others interested in such a program, it may be necessary that the personnel carry on an educational compaign, designed to instruct and interest the various groups involved, as to the importance of the problem, in an effort to further the program. It has been the experience of health departments that the best way to conduct work in industrial hygiene is to cooperate fully with industry, conducting studies in plants, as a rule, only upon request of industry. At the completion of such studies a confidential report on the results should be presented to the plant officials, with recommendations for the improvement of conditions, if such information is necessary and available. All this should be made very clear to the individuals concerned, in order to obtain the cooperation and aid necessary for such work.

3. Studies of the workroom environment and the health of workers by the industrial-hygiene personnel as outlined in 2.

4. In order to carry on this work with the minimum amount of friction and in a spirit of cooperation, it may be necessary to provide a law or regulation which specifically states that the results of any investigation made by the health department can in no way be used in litigation, either by the employer or by the employee. The need for such a ruling is obvious if the interests of all concerned are to be served justly. Attention is called to the act under which the Bureau of Occupational Diseases of the Connecticut State Department of Health functions, as well as to the excellent work this Bureau is accomplishing in the control of occupational diseases in that State.

The additional cost for maintaining industrial-hygiene personnel of the number and type given would not exceed $10,000 a year, or slightly more than 1 cent per capita in the present case. When one realizes the fact that 1 case of silicosis often costs more than the $10,000 needed for a preventive program of the type outlined, the financial phase of the problem should certainly not preclude the establishment of such a vital adjunct of a health department in a large industrial center.

In closing, it is well to emphasize one important point--namely, that occupational diseases are in a large measure preventable, and the degree of prevention exercised by a community will be reflected in the general health status of that community.

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